EVOLUTION OF LIFE

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Dedicated to

Dr D. N. Wadia, F R S

Father of Indian Geology and
National Research Professor
India

PREFACE

In 1859 Charles Darwin (1809–1882) published *The Origin of Species* in which he organized numerous well-observed facts and presented a synthesis which documented the theory of evolution in a unique manner On July 1, 1858 he had already presented a joint paper along with Alfred Russell Wallace (1822–1913) before the Linnaean Society of London embodying the theory of evolution of which the struggle for existence, variation and natural selection of variations were the three principal factors *The Origin of Species* paved the way for the general acceptance of the fact of evolution It provided a new understanding of life and the planet on which the drama of life is being enacted Man's place among living organisms was indicated It clarified what was obscure and simplified a vast maze of facts which fell into a new pattern The publication of *The Origin of Species* was a great event in the history of human thought Since then evolution became the key idea in Biology and ultimately it extended into the realm of the inorganic How particles of energy organize into atoms and atoms into elements, is the saga of Physics and Chemistry How the Solar System with the sun and its planets evolved from a gaseous nebula is a part of the same saga Now it is realized that evolution is an all-pervading process which has resulted in forms with a higher organization than their predecessors Organisms have changed in the course of history of the earth and this change has been generally progressive

All great generalizations have a parentage of antecedent thought and observation and the theory of evolution is no exception to the rule Sir Charles Lyell the geologist had already stated in 1832 in his *Principles of Geology* that the age of the earth was to be calculated in millions of years This provided the time span which was needed to explain the evolution of species from lower to higher levels of organization and incidentally exploded the Jewish-Christian myth that the world was created in 4004 B C That Lyell had also realized that life has evolved is indicated by the following excerpt from a letter which he wrote in 1836 to Sir John Herschel

"When I first came to the notion of a succession of extinction of species, and creation of new ones, going on perpetually now, and through an indefinite period of the past, and to continue for ages to come all in accommodation to the changes which must continue in the inanimate and habitable earth the idea struck me as the grandest which I had ever conceived, so far as regards the attributes of the Presiding Mind' In 1838

Charles Darwin read Thomas Malthus' essay *On Population* in which Malthus had stated that human population tended to increase faster than its food supply, resulting in a struggle for existence It gave him the idea of natural selection as a result of the struggle for existence and the survival of the fittest

Charles Darwin's grandfather Erasmus Darwin (1731–1807) had already propounded in his *Zoonomia* that all animals undergo transformation "The world has been evolved, not created' he observed "It has arisen little by little from a small beginning, and has increased through the activity of the elemental forces embodied in itself, and so has rather grown than suddenly come into being at an almighty word" He further believed in the inheritance of acquired characters

Sir Gavin de Beer states that the concept of evolution in its modern sense is French in origin The term 'evolution' was used for the first time in its modern meaning by Etienne Geoffroy Saint-Hilaire in his *Memoire sur les Sauriens de Caen*, published in 1831 He regarded environmental influence as the sole cause of evolution He also anticipated Hugo de Vries by holding that change from one species to another might be by saltations Before him Jean-Baptiste de Monet de Lamarck (1744–1829) while classifying plants and animals in the Museum National del'-Histoire Naturelle, Paris, concluded that species could be linked in finely graded series He gave the conception of phylogeny or a tree of life He constructed a system in the form of a genealogical tree, beginning with the Protozoa and ending with man himself, with branchings indicating the common origins of diverse groups of animals He also gave the name of Biology to the science which concerns itself with living things Lamarck's *Philosphie Zoologique* published in 1809 contains his final statement upon his evolutionary hypothesis which is based on the inheritance of acquired characters

The principal factors in Darwin's theory of the origin of species are the struggle for existence, variation, and natural selection of those variations which are better adapted than others to the environment and the ecological conditions in which the individuals of the species live Natural selection operates automatically letting through the best adapted and rejecting the others

There are three primary questions regarding evolution Is evolution a fact, and if so, how and why does it take place? The greatest contribution of Darwin lies in proving that it is a fact He marshalled evidence regarding comparative anatomy, embryology, geographical distribution of plant and animal species, and above all palaeontology Palaeontology was then an infant science and the geological record was notable for gaps Commenting upon its imperfection Darwin observed in 1859, "I look at the natural geological record as a history of the world imperfectly kept, and written in a changing dialect, of this history we possess the last volume alone, relating only to two or three

countries. Of this volume only here and there a short chapter has been preserved; and of each page, only here and there a few lines." Since then, on account of extensive exploration the world over, a number of gaps have been filled. We have now more comprehensive data on the evolution of the horse, the elephant, the camel, the rhinoceros and man. Further, the application of the Carbon-14 method of dating for geological strata has made it possible to measure the speed of evolution. Thus it took two million years for the transition from one species to another in the phylogeny of the horse, and 60 million years to transform a mammal of the size of a sheep into the horse.

As regards the mechanism of evolution, Darwin in his theory of the natural selection of hereditary variations gave a plausible explanation which has been amended only in detail with the progress of science, particularly as to the role of chromosomes as the bearers of heredity, as later discovered by Mendel and subsequently refined by numerous geneticists.

The third question relates to the cause of evolution. Why does evolution take place? Nobody has been able to provide an answer to this question. Moreover, here we stray into the realm of philosophy. In this book, we are more concerned with the fact of evolution as revealed by geology, palaeontology and palaeobotany. An astonishing array of facts have been revealed by modern research regarding the past history of the earth and the life it supported through the ages.

My interest in the subject of Evolution of Life was greatly stimulated by the writings of Dr D. N. Wadia, doyen of Indian geologists, and at present Mineral Adviser to the Government of India, to whom this book is dedicated. I recall with pleasure many hours spent in his pleasant company discussing the problems of Gondwanaland and the birth of the Himalayas. I felt that the information about the geological past of India which he had given in his popular papers and pamphlets was so important that it should reach all educated Indians. In the books available on this subject, it is the fossils of Europe and America which figure prominently. British and Indian geologists have done a good deal of work in exploring the fossils of India, but unfortunately much of this knowledge has remained buried in the journals and memoirs of the Geological Survey of India. It was the realization of this fact that led to the writing of this book. Though the idea of this project has been in my mind since 1940, the immensity of the task and its intricate nature was a deterrent.

An opportunity came in 1961 when I was appointed Adviser to the Planning Commission, on Natural Resources and Scientific Research. This position put me officially in touch with all scientific organizations in India including the Council of Scientific & Industrial Research, the Geological, Botanical, Zoological and Archaeological Surveys of India, the Oil and Natural Gas Commission and the Birbal Sahni Institute of Palaeobotany.

On May 1, 1963, I suggested to Dr Husain Zaheer, the then Director-General, Council of Scientific & Industrial Research that a book be published by the Council giving an account of the evolution of life with reference to the background of the geology of the Indian sub-continent He accepted this request with his characteristic magnanimity.

On August 19, 1964, I was appointed Chairman of a committee which among others included Mr Jagjit Singh, Dr A K Dey and Dr Vishnu Mittre Mr Jagjit Singh is General Manager of the South Eastern Railway, Calcutta, and is deeply interested in physics, astronomy and mathematics He won the UNESCO Kalinga Prize for science popularization in 1963 Dr A K Dey was Superintending Geologist, Geological Survey of India for a long time and was associated with me as Mineral Adviser in the Natural Resources Division of the Planning Commission He specializes in the palaeontology of India and is the author of *Minerals of India*, an authoritative text on the subject Dr Vishnu Mittre is a palaeobotanist, working in the Birbal Sahni Institute of Palaeobotany, Lucknow, and has a large number of papers on this subject to his credit

When four authors collaborate, their contribution is bound to be unequal Mr Jagjit Singh contributed the first four chapters which deal with the universe and its origin, stellar evolution, the solar system, and the question of possible life in other worlds The task of planning the rest of the book, selection and organization of illustrations, fell upon me Its nucleus is to be found in a series of articles describing the evolution of life from the Archaeozoic to the Jurassic Period which I wrote for the journal *Everyday Science* in 1952. The account of the origin of life (pp 39–53) in the chapter on the Archaeozoic Era has been provided by Dr M S Swaminathan, who is a well-known geneticist, and is at present Director of the Indian Agricultural Research Institute, New Delhi The subject of vegetation in the chapters dealing with the Cretaceous and Tertiary Periods has been the responsibility of Dr Vishnu Mittre He has also amplified the descriptions of fossil plants in the earlier chapters Dr A K Dey has provided an account of animal fossils as well as of palaeogeography and geology from the Cretaceous to the Tertiary Chapters twentyone to twentyfour and the resume have been written by me

Usually books on the evolution of life end with the emergence of man Here I have adopted a different approach, and apart from discussing the evolution of man in the light of the most recent findings of research, I have also explained the evolution of his material culture up to the Chalcolithic age This is necessary so that the evolution of man and his culture is firmly linked with the evolution of his animal ancestors Moreover, the findings of modern archaeology, assisted by the Carbon-14 dating method and by palynology, about man's material progress, such as the domestication of plants, are as spectacular as those of geology Besides I felt it necessary to provide history with the perspective of geological time so that historians realize how brief is the span of human history. When

one considers the vicissitudes through which living beings have passed in the long geological history of the earth, the troubles which the present generation is facing seem insignificant The findings of geology provide a new background to human history and impel us to discard the old ideas of the golden age in the past, for it has been shown that the material environment of man has progressively improved through the ages and the consumer goods which are now enjoyed by the common man were not available even to kings in the past It is felt that this approach will provide the necessary corrective so that history is not over-laden with inconsequential details about kings and their wars and they attempt to give us a history of man and his culture

The structure of the chapters is as follows Firstly an account is given of the geology and distribution of the rocks of the period in other parts of the world followed by a description of their occurrence in various parts of India as well as their characteristics Then follows a brief statement of the relevant palaeogeography, giving the configuration of continents in that particular period as well as an account of climate This is succeeded by a description of important plant fossils with a resume of the advances made in plant life Finally, a review is presented of animal fossils, ending with a brief mention of major evolutionary advances

The text is copiously illustrated with maps revealing the configuration of continents in the past, distribution of rocks in India, palaeoscapes showing plant and animal life, and photographs of rock exposures or sections of geological interest and fossils A number of illustrations are original Most of these have been provided by the Indian Council of Agricultural Research, an organization of which I was the Chief during 1955–1960

It is for the first time that such a synthesis is presented for the benefit of readers in India and of those in adjoining countries who share their past with her The facts are not new but the synthesis is It is here that the importance of this book lies Its aim is to portray the evolution of life and man to readers in this country, no longer as a remote phenomenon but as one which they can understand and appreciate from the fossils, rocks and vegetation of their own country It should also promote a better understanding of mountains, rivers, soils, vegetation and fauna of India

Considering the magnitude of the task, none could be more aware of the imperfection of this synthesis than the editor and the principal author In such a work it is as important to decide what should be omitted as what should be included My effort has been to provide an account of the past history of this planet and the life it supports as succinctly as possible, so that the main picture of evolutionary advances in plant and animal life is not blurred by unnecessary detail I also had the requirements of the non-specialist reader in view, so that this knowledge, which has so far been the preserve of the specialist, reaches him At the same time my concern has been to provide an account

CONTENTS

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of the evolution of life, which while generalized and simplified, should none the less command the respect of experts How far my colleagues and I have succeeded in this task is for the reader to judge I earnestly hope that persons who are better qualified than us will in due course, improve upon this text so that it becomes more authentic It would also be worthwhile to cull out a general simplified account of the evolution of life from this book and to translate it into the regional languages of India so that this most essential knowledge reaches a wider audience This is particularly necessary in a country of which the greater part of the population is still clinging to the past and is steeped in ignorance and superstition

Success in a venture such as this depends upon co-operation at the international as well as the national level I have been fortunate in receiving generous co-operation from many quarters Most of the illustrations for the first two chapters have been given by the Mt Wilson and Palomar Observatories, USA The American Embassy in New Delhi provided photographs of the surface of the moon and of Mars The Embassy of the USSR, New Delhi gave a picture of the dark side of the moon taken by their Zond III Through the kind intervention of Prof John Kenneth Galbraith the American Museum of Natural History, New York, the Chicago Natural History Museum, and the Buffalo Museum of Science, New York, supplied photographs of palaeoscapes which have greatly added to the value of this book The Geological Survey of India (GSI) loaned photographs of animal fossils as well as of rock sections from different parts of India Mrs Savitri Sahni, President of the Birbal Sahni Institute of Palaeobotany, Lucknow, generously gave photographs of the type fossils of plants in the collection of the Institute as well as of some of the palaeoscapes I am also indebted to the Geology Department of the Panjab University, Chandigarh, for the photographs of the Siwalik mammals in their collection The Indian Council of Agricultural Research as well as the Forest Research Institute, Dehra Dun gave photographs of vegetation types Mr B B Lal, Director of the Archaeological Survey of India, extended his whole-hearted co-operation to me by allowing the use of maps showing the spread of pre-historic cultures, and by giving photographs of stone and copper implements discovered in India My thanks are also due to all the publishers and authors who have allowed me to use illustrations published in their books These have been acknowledged in the captions as well as in the lists of plates and figures I am particularly grateful to UNESCO for allowing me the use of illustrations, maps and charts from their publication, *History of Mankind*, Vol 1, *Prehistory and the Beginnings of Civilization* by Jacquetta Hawkes and Sir Leonard Woolley (London 1963) For the account of the evolution of man and his material culture I have mainly relied on this book My indebtedness to Prof J D Bernal for his excellent *Science in History* is obvious I am grateful to Dr Atma Ram the present Director-General of the Council of

Scientific & Industrial Research, for his support to this project I also record my gratitude to Messrs S B Deshaprabhu and R C Sawhney for the pains they have taken in the production of this book, and to Dr S R K Chopra, Professor of Anthropology and Dr G P Sharma, Professor of Zoology, Panjab University, Chandigarh, for reading the proofs and giving many helpful suggestions

Chandigarh
January 29, 1969

M S RANDHAWA

CONTENTS

THE CENOZOIC ERA

LIST OF ILLUSTRATIONS

PLATES

FIGURES

CHAPTER ONE

THE UNIVERSE AND ITS ORIGIN

THE ORIGIN of the universe, the central problem of cosmology, is a primeval mystery that will take long to divine. Nevertheless, modern cosmologists have begun to formulate at least provisional answers to this ancient human enigma by piecing together a large body of observational data by means of astrophysical and mathematical reasoning. The wonder is not that the answers given are in flat contradiction with one another but that there are any answers at all no matter how provisional or contradictory. Before we record some of them here, let us pull the veil of heavens aside to see what there is in the universe. Looking out into the depths of space from our earthly abode, we see the moon a little more than a second away, and the sun about eight minutes. Here, as is customary in such cases, we reckon distances not in miles but in terms of the time their light, moving at the rate of 186,000 miles a second, would take to reach us. Farther away, within distance ranges varying from a few light minutes to a few light hours, we may spot the planets of our solar system, whose remotest member, Pluto, is about five light hours away (Pl 1, A).

Beyond the solar system, there are the fixed stars—"fixed" because they are so remote from us that their own motion does not materially affect their apparent position in the sky as seen by us. These stars are bodies more or less resembling our own sun but immensely remote from us and from one another. In the neighbourhood of our sun they are, on the average, about 5 light years distant from their nearest neighbours, but as one goes in toward the centre of the galaxy the stars are much more crowded together and may, indeed, be separated from each other by no more than a fraction of a light year.

Most of the stars we see seem to be concentrated in a bright band of light called the Milky Way. The reason for this concentration of stars in one particular region of the sky is that we are located in a huge group of stars that is shaped like a gigantic wheel or disc as shown in Pl 1, B. The diameter of this disc is about 90,000 light years, but it is only 3000 light years thick near its outer rim, in our neighbourhood, though it is about five times thicker at its centre. Hence, when we look along the radius of the disc, that is, along the galactic plane, we are looking in a direction that is studded with stars along a line thirty times as long as when we look in the perpendicular direction, that is, in the direction of its thickness or the galactic poles of the Milky Way (Fig 1). Surrounding the disc and

extending to distances about three times its radius is a great diffuse halo of stars This huge system is known as the galaxy.

The galaxy, however, is no mere collection of stars sprinkled over immense distances New techniques of observation, like those of radio astronomy, have now shown conclusively that it is pervaded by an extremely thin substratum of invisible interstellar matter in the form of cosmic dust and gas of exceedingly low density Earlier astronomers who observed the Milky Way during the first thirty years of the present century had no means of detecting it This is why they were haunted by this ghost of a material which while it could not be directly observed nevertheless made its presence felt in many indirect ways We now have thanks to radio astronomy, extremely powerful means of directly observing these invisible interstellar gas clouds Thus, the major constituent of interstellar gas—neutral hydrogen—shows itself by the emission of radio noise emitted at 1420 megacycle frequency (21 cm wavelength) In fact, observation of 21 cm "radio" radiation from the Milky Way has been so successful in revealing the presence of neutral hydrogen in interstellar space that the observations of 21 cm radio noise coupled with Oort's theory of galactic rotation has given us a complete picture of the distribution of neutral atomic hydrogen in our Milky Way system It is now believed that the interstellar matter consists on the average of 1 per cent dust to 99 per cent gas, mostly neutral hydrogen atoms The total mass of interstellar matter in the galaxy is only 2 per cent of its total mass of about 100 billion suns This amounts to an average density of one atom per cc although there are many regions of denser concentrations where it may be ten to twenty

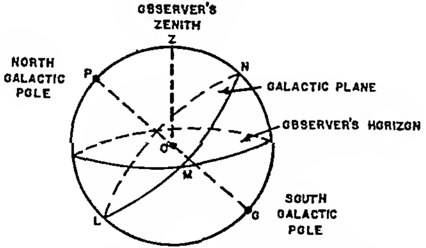
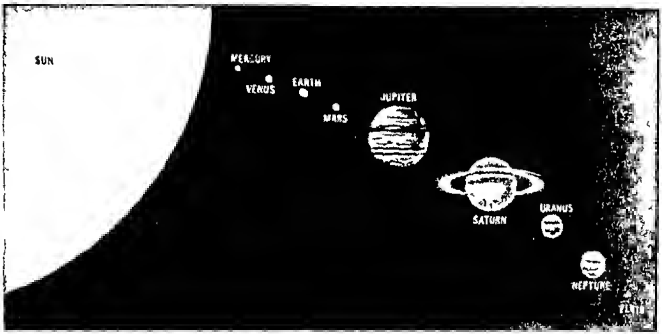
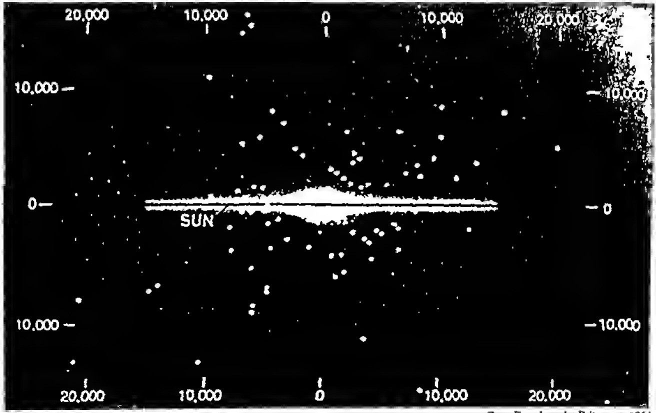


FIG 1 THE SPHERE IS THE OBSERVER'S SKY THE LINE LMN IS THE PROJECTION ON THE SKY OF THE MILKY WAY LINE OR THE GALACTIC PLANE POINTS P AND Q ARE THE GALACTIC POLES THE GALACTIC PLANE IS THE COUNTERPART OF THE TERRESTRIAL EQUATOR IT CAN BE USED TO DEFINE THE POSITION OF ANY CELESTIAL OBJECT ON THE SKY BY MEANS OF TWO NUMBERS ITS GALACTIC LONGITUDE AND LATITUDE (From Jagjit Singh 1961 Dover Publications New York)

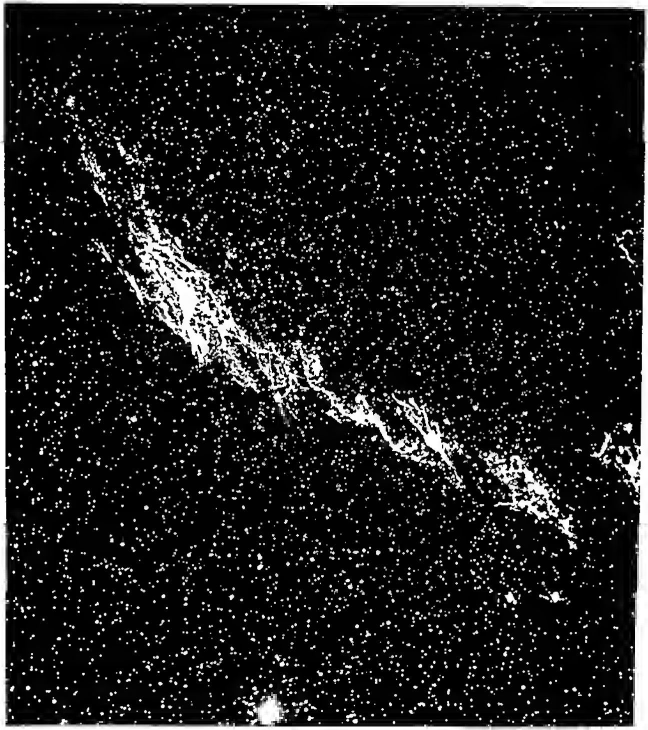


A PLANETS OF THE SOLAR SYSTEM, SHOWN ACCORDING TO THEIR RELATIVE SIZES AND ARRANGED IN ORDER OF THEIR DISTANCES FROM THE SUN



From Encyclopaedia Britannica, 1964

B. MODEL OF THE MILKY WAY — OUR OWN GALAXY



Photograph from Mt Wilson and Palomar Observatories

NETWORK NEBULA IN CYGNUS

times greater Even these regions of comparatively high concentrations of interstellar gas are rarer than the most rarefied vacuum we can create in any laboratory But on the cosmic scale these vacua—regions of high concentrations—make their presence known quite readily in the form of dark or luminous nebulae The former appear as dark patches interrupting the rich star fields that can be observed in the Milky Way even with a small telescope A case in point is the Coalsack nebula near the Southern Cross This fact together with the appearance among them both of bright and dark patches and still darker globules shows that they are real dark clouds rather than starless 'holes" in heaven Indeed, astronomers have now devised ways of even measuring the absorptions, distances, and thicknesses of these dark clouds, the dark nebulae, by measuring the apparent distances of stars both through a cloud and in a neighbouring field outside the cloud

Luminous nebulae too are easily distinguished For while the stars always appear as more or less bright points both to the telescope and the naked eye, luminous nebulae look like diffuse nebulosities even on photographs taken with the largest telescopes These luminous nebulosities, the galactic nebulae, are of two main types First, there are the irregular, diffuse nebulae which are sometimes drawn out in long filaments like the Network Nebula in Cygnus (Pl 2) Secondly, there are small disc-shaped symmetrical formations like the Ring Nebula in Lyra, with well-defined edges similar to the images of the planets like Uranus and Neptune of our solar system (Pl 3) But they are definitely not planets because they remain as fixed on the vault of the heavens as any of the fixed stars Nevertheless, their superficial resemblance to the planets has earned them the misleading name of planetary nebulae

The galaxy with its stars, globules, nebulae, dust and gas clouds is by no means the end of what we can observe in the heavens. It is in fact merely the end of a new beginning For there are in the sky hundreds of billions of telescopic objects which also look like diffuse nebulae but these are situated far beyond the limits of the galaxy. Indeed, they are themselves galaxies, that is, immense conglomerations of stars and nebulae very similar to the galaxy in which our solar system is located

Thus completes the list of actors that according to the current school of cosmologists are concerned in the drama of the cosmos But it now seems likely that the cosmic play they tried to produce may well be very much like Hamlet without the Prince of Denmark For among some of the radio sources, we have recently discovered, are star-like objects called quasi-stars or quasi-stellar radio sources or simply quasars Although in size no more than ordinary stars, they are a hundred million times as heavy as the sun They radiate energy at a rate three hundred billion times that of the sun so that their power output exceeds that of a giant galaxy They are among the remotest objects in the universe hitherto identified Their discovery in 1962 caused considerable excitement in astrophysical circles

as their behaviour is so curious that no theory is able to account for it. In particular, no known process of energy generation can sustain their prodigious outpourings of radiation into space. They are possibly among the remotest objects in the universe, hitherto identified being situated at distances equal to several billion light years at the very edge of our observable universe (Fig. 2).

Now seeing the universe of stars, nebulae, globules, galaxies, quasars, etc. the natural question to ask is how did it all begin and how is it all going to end. It is a question that palaeolithic man asked as he looked at the star-spangled heavens and it has baffled the modern astrophysicist exploring the sky with giant optical and radio telescopes of today. We do not yet know the answer. But a convenient take-off point for our account of cosmological speculations of today may well be Hubble's astonishing discovery about the galaxies. Hubble showed some forty years ago that spectral lines emanating from all the distant galaxies are shifted towards the red end of the spectrum and that this red-end shift increases directly with distance. Now a red-end shift of spectral lines of a celestial object means, according to the well-known Doppler interpretation, that it is receding from us. Hubble's observation therefore shows that all the distant galaxies are moving away from us at velocities proportional to their distances from us (*see* Pl. 4 and Fig. 3). The detailed studies made by Hubble and his collaborator Humanson led to what is now called Hubble's law. It is merely a statement that the recession velocity (v) of a distant galaxy

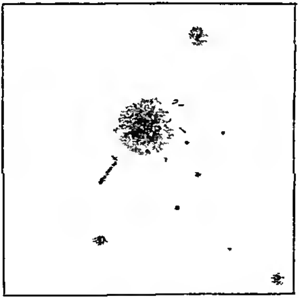


FIG. 2. THE QUASAR 3C273. Note the jet which points away from the star-like object. Although its distance is 1.8×10^9 light years this object is easily seen through an amateur's 6" telescope (After Hong Yee Chiu *Physics Today* 1964, 17(5) 24, Fig. 5. Original photo by A. R. Sandage)

Photograph from Mt. Wilson and Palomar Observatories

RING NEBULA IN LYRA

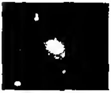
RELATION BETWEEN RED-SHIFT AND DISTANCE FOR EXTRAGALACTIC NEBULAE

CLUSTER NEBULA IN — DISTANCE IN LIGHT-YEARS — RED-SHIFTS

VIRGO

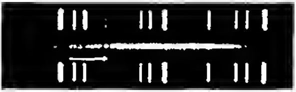
7,500,000

750 MILES PER SECOND



URSA MAJOR

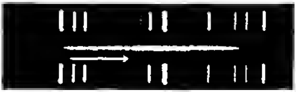
100,000,000



9300 MILES PER SECOND

CORONA BOREALIS

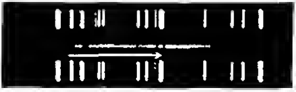
130,000,000



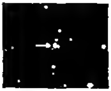
13 400 MILES PER SECOND

BOOTES

230,000,000



24 400 MILES PER SECOND



HYDRA

350,000,000

38 000 MILES PER SECOND

Photograph from Mt Wilson and Palomar Observatories

RED-SHIFT

The distances in light years should now be increased by a factor of about 6× in the light of recent knowledge. Red-shift figures are not affected

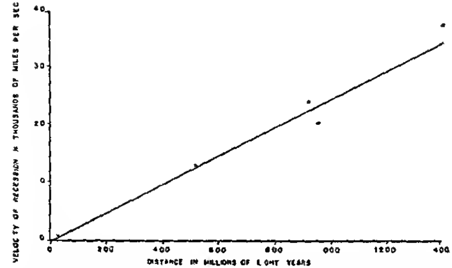


Fig 3 Velocity distance chart for galaxies (From Jagjit Singh 1961 Dover Publications New York)

increases in direct proportion to its distance (d) epitomized in the equation, $v=Hd$, H being a constant of proportionality known as Hubble's constant.

Consider any galaxy (G) at distance d_1 from us According to Hubble's law it is receding from us with velocity $v_1 = Hd_1$ If it has been doing so at this rate all the while, it would have travelled the distance d_1 from us in time $d_1/v_1=d_1/Hd_1=1/H$ In other words, at a definite epoch of time $1/H$ years ago the galaxy G was at our present location Since H is a constant, the same for all galaxies, what is true of the galaxy G holds equally for all of them It, therefore, follows that all the extant galaxies were practically coincident with our present position $1/H$ years ago This epoch of coincidence, when the universe was apparently in a state of unimaginably hyperdense concentration with all its matter packed within a pin-point, has been interpreted as the "creation" of the universe and the reciprocal $(1/H)$ of Hubble's constant as its "age" No doubt the inference we have sought to deduce from Hubble's law presents at first encounter such serious conceptual difficulties that it is hard to swallow But it is precisely such a "singular" state of hyperdense concentration that was predicted by theory even before Hubble formulated his law For, at the time Hubble was making his observations the Russian mathematician Friedmann was applying Einstein's relativity equations to solve the cosmological problem He showed that on the basis of Einstein's relativity equations our actual universe could do only one of two things Starting from an initial state of hyperdense concentration of all its material content within the eye of a needle such as Hubble's law seems to suggest, it will either go on expanding or oscillating In one case the expansion goes on for ever In the other it oscillates, expanding in one phase and contracting in the other

We can in principle decide whether our universe conforms to the expanding or oscillating model, in two ways First, we may extend Hubble's observations to see whether or not his law of proportionate increase of recessional velocity with increasing distance continues to hold indefinitely or at any rate to the very threshold of our barely visible horizon But here, as Hubble himself justly remarked, our "knowledge fades" and we are obliged to "search among the ghostly errors of observations for landmarks that are scarcely more substantial". The latest provisional finding of Sandage working on these lines is that the law of proportionate increase with distance holds, except possibly at the very limit of the observable universe where red-shifts are of the order of one-fifth the velocity of light and distances are of the order of a billion light years At this point it seems that the red-shifts are getting longer than expected on the basis of Hubble's law If the effect is real and correctly interpreted, it implies that the expansion is slowing This paradoxical result follows from the fact that the deeper we probe into intergalactic space the farther back in time we see Thus, if the most distant galaxies are found to be receding faster than anticipated on the basis of Hubble's law, then expansion in our part of the universe has slowed down during the last billion years If so, our universe may well conform to the oscillating model

Alternatively we can resort to theory to decide whether the expansion we observe at present will continue indefinitely or will slow down sufficiently to stop and reverse itself. We can do so by comparing the kinetic energy of expansion with the potential energy of gravitational forces acting between the galaxies, exactly as we may decide whether a bullet fired vertically upwards will or will not escape from the gravitational pull of the earth If the former, that is, the kinetic energy of the expansion is greater than the potential energy of the gravitational forces, the expansion will never stop If not, expansion will peter out and reverse itself Calculation shows that the ratio

$$\frac{\text{Kinetic energy of expansion (k)}}{\text{Potential energy of gravitation (u)}} = \frac{27\ H^2}{200\ \pi G \rho}$$

where G is the constant of gravitation, ρ the average density of matter in the universe Now, of the four constants determining the ratio k/u, the values of only two, viz π (the ratio of the circumference of a circle to its diameter) and G the gravitational constant are known with any degree of reliability The values of the other two, viz H and ρ are still very uncertain Various estimates given are revised from time to time Thus at one time the value of 1/H or the "age" of the universe was assumed to be as low as barely two billion years But subsequent revisions have raised it successively to five, seven, ten and now to seventeen billion years Adopting the present (provisional) values of H and ρ, the ratio k/u is found to be about 1000. In other words, the kinetic energy of expansion is estimated to exceed the potential energy of gravitational attraction by a factor of about one thousand

Consequently the expansion may be expected to last for ever without reversal But this conclusion that the galaxies will continue to recede is likely to hold only if there is no serious revision in our present estimates of $1/H$ and ρ, particularly the latter For example, if future observations reveal the existence of undetected matter in the huge putatively vacuous spaces between galaxies, it may very well increase the value of ρ by a factor of one thousand In that case the ratio k/u will become less than unity requiring that the expansion of galaxies must halt in future and reverse itself

Since neither alternative leads to a firm conclusion, we may explore another line of evidence that has lent a measure of qualified support to the expanding (oscillating) universe theory, viz modern nuclear research into the origin of elements This research has shown that heavy elements can be built up from lighter hydrogen and helium elements only in conditions of extremely high density and temperature As we shall see in the sequel, the nuclei of atoms of helium, carbon, lithium, calcium, silicon, iron and the like are synthesized in the extremely hot interiors of the stars Thus the transmutation of hydrogen into helium requires a temperature of about 20 million degrees that prevails in the stellar interiors The transmutation of helium into lighter atoms like carbon, oxygen and neon needs a temperature of 100 million degrees and that of lighter atoms into elements of medium atomic weight like iron, silicon and so on, a yet higher temperature range of 1 to 2 billion degrees Such temperatures do arise in the interiors of stars at certain times during the course of their evolution But the further consolidation of these medium weight atoms into yet heavier atoms like lead, radium and the like, demands a still higher temperature of several billion degrees Even the stellar interiors of the hottest stars are not hot enough to cook them Considering that their buildup requires far more Draconian conditions than even the stellar interiors provide, where and when could they have been baked?

Gamow suggests that the expanding (oscillating) models of relativity theory provide a possibility of a place and time at which such extreme conditions could have prevailed If the universe did originate from the fragmentation of a primeval atom in which all the material of the universe was originally condensed, the initial state of the universe at the epoch of its "creation" $1/H$ years ago could have led to the forging of at least the bulk, if not, all the heavier elements we find in the universe today For according to Gamow, in the state of hyperdense concentration at the first dawn of its "creation", the universe was a blaze of a veritable noontide of light, radiation and lustre that could only be equalled by the cumulative splendour of exploding galaxies of supernova stars But such a cosmic flood of fire soon spent itself Taking its temperature T as a measure of its fury, Gamow showed that T would fall rapidly with time t reckoned in seconds according to the formula

$$T = \left(\frac{15\times 10^9}{\sqrt{t}} - 273\right) {}^\circ\mathrm{C} \qquad (1)$$

Consequently T tumbled from about 500 billion degrees a microsecond after the explosion to a mere billion degrees five minutes later. Within a day it further dropped to 40 million degrees but took 300,000 years to fall to 6000 degrees and 10 million years to cool down to room temperature. It would thus appear that for the first few moments of its existence after the primeval explosion the universe was at a temperature sufficiently high to spark nuclear reactions During this very early stage of the universe matter must have been completely dissociated into elementary particles, being a mixture of free electrons, protons and neutrons.

As the temperature began to drop, each proton promptly captured a neutron, the pair forming a deutron, a species of hydrogen Some deutrons then captured another neutron and became what is called hydrogen-3 This nucleus soon decays by emitting a negative electron and is thus transmuted into helium-3 In this way, by a rapid succession of neutron captures and electron decays, all the elements could have been built up in the first burst of the universe's expansion provided there were some mechanisms for bypassing helium-5. Although we can produce helium-5 in the laboratory by bombarding helium-4 with neutrons, it immediately breaks down to helium-4. The absence of a stable helium-5 is a serious difficulty facing Gamow's theory. Gamow is, therefore, obliged to concede that "while a small amount of heavy elements must have been produced during the early stages of expansion, the main bulk of them in their present abundances was synthesized later by some other process such as during supernova explosions". Gamow calculates that the whole process lasted barely thirty minutes, for by that time the temperature of the expanding universe must have dropped below the threshold of thermonuclear reactions among the light elements

While cosmic matter was thus forged within the first few minutes of the creation's birth, it remained a prisoner at the mercy of thermal radiation for a long while. As already noted, it took 300,000 years for the temperature of the universe to drop to 6000 degrees, the temperature at the surface of the sun Although at this date the fury of the primeval flood of fire that gave cosmic matter its birth had abated more than a hundred million-fold, the temperature of thermal radiation was still high enough to require attention to a feature that is of no consequence under ordinary conditions This feature is the ponderability of radiant energy or light quanta For according to Einstein's equivalence principle, radiant energy E possesses a ponderable (i e gravitating) mass which is numerically equal to the quotient of energy (E) divided by the square of the velocity of light (c) In symbols, mass (m) of the radiant energy E of light quanta is given by $m=E/c^2$. Under ordinary conditions of our daily life, the "weight" of light is negligible. Thus, the total weight of light quanta traversing one cubic kilometre of atmospheric air at ordinary temperature such as may obtain on a bright sunny day is only one hundred millionth (1/100,000,000)

of a gramme. But it increases rapidly with temperature (T), being proportional to its fourth power (T^4) Consequently at very high temperatures such as prevail in stellar interiors or in the case of exploding atomic bomb, the weight of light quanta (which in this case are high frequency gamma rays) may be as high as one gramme per litre Since the temperature T of the universe in the beginning was very high according to formula (1) the density of radiation at that time must have been much greater than it is now Gamow's calculation of the changing densities of radiation and matter with time is shown graphically in Fig 4 The ordinate represents densities of radiation and matter in grammes per cc, while the abscissa represents the time in seconds since the primeval explosion, both on the logarithmic scale for the sake of convenience of representation As will be observed from Fig 4, it was only after the lapse of about 1700 million years, one-tenth the putative age of the universe, that the universe cooled off sufficiently to make the densities of radiation and matter equal In other words, while radiation prevailed over matter during the first 10 per cent of the history of the cosmos, matter has prevailed ever since It is only after the

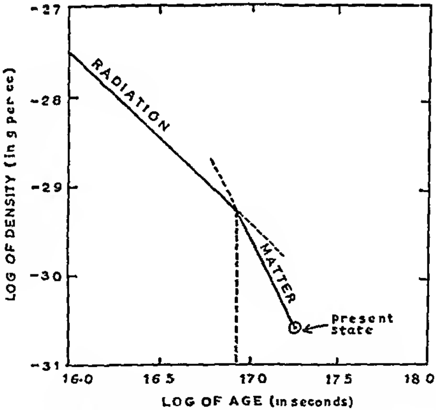


FIG 4 CHANGES OF RADIATION AND MATTER DENSITIES IN VARIOUS STAGES OF THE EXPANDING UNIVERSE (From Gamow, in The Universe and its Origin 1964 Macmillan & Co Ltd London)

transition from the reign of radiation to that of matter during the remaining 90 per cent of cosmic history that the evolution of galaxies began to occur For, at this time some 15 billion years ago the densities of radiation and matter became approximately equal to one another with the temperature of space falling to about —223°C and the density of matter (or radiation) to 3 10^{-30} grammes per cc, which is higher than the present density of matter in the universe (2 atoms of hydrogen per cubic metre) by a factor of ten At this stage further expansion made matter gravitationally more important than radiant energy and gave rise to the first step in the differentiation of the originally homogeneous gas

It thus seems that some 15 billion years ago the state of the universe was an extremely tenuous gas mostly of hydrogen atoms spread throughout space of a density of approximately two atoms per cubic metre of volume As a density it is a mere figure of speech, for a cosmic cloud of this density and of the size of our sun would weigh less than a tumbler of water But even such a state of extreme tenuity, when ranging over distances of the order of billions of light years, would suffice to provide material enough for all the extant galaxies

The evolution of such an extreme tenuity into the universe of galaxies and stars we know is still a challenge to human thought But before we describe present day attempts to meet it we may interrupt our account of the modern genesis to mention that the big bang theory of Gamow outlined above is not free from some serious objections The absence of a stable atom of mass 5, helium-5, already noted earlier is only one of them Another is the age discrepancy Astrophysical theories of the evolution of galaxies and stars seem to show that many of them are paradoxically enough older than the universe Thus the age of globular clusters in the Milky Way is reckoned to be of the order of 25 billion years Hoyle, Bondi and Gold have, therefore, proposed a new revolutionary hypothesis According to it, the recession of galaxies does not lead to continual rarefication of matter in cosmic space since new matter is continuously created out of nowhere at a rate which just compensates the dilution due to expansion From this newly created matter new galaxies are born continuously so that the total number of galaxies in any given sufficiently large volume of the universe remains the same at all times This is a way of saying that there is neither beginning nor end of the universe as a whole It continues to present the same large scale aspect to all observers at all times from all locations Since new galaxies are formed to replace those drifting away on account of the universal recession, it follows that galaxies forming our observable universe are not of the same age as in the big bang theory On the contrary, they represent a widespread age group, from very young ones to very old ones

Although many astronomers do not subscribe to the steady state theory because of its *ad hoc* character, it cannot be said to be as yet definitely *hors de combat*, the evidence pro

and contra being rather inconclusive at present These difficulties of the big bang and steady state theories have given rise to a host of new cosmologies so that cosmology is quite literally now in its hundred flower bloom After all, the universe is very large and not enough is known about it Given sufficient ingenuity almost anything can be explained or explained away This is why a wide diversity of ideas from various fields like physics, chemistry, nucleogenesis, geology, astrophysics, radioastronomy, etc may be borrowed to plant almost any "exotic" bloom in the cosmological garden For example, Dirac and Jordon have reared a cosmology on the novel idea that universal constants of nature like the constant of gravitation G are not true constants but vary with the 'age' of the universe Likewise, Bondi and Lyttleton have founded a cosmology on the assumption of a very slight departure from the usual belief that the electron and proton charge magnitudes are exactly equal Kapp built up a cosmology on a further extension of Hoyle's hypothesis of continuous creation by postulating that matter is not only being continuously created out of nowhere but is also continuously disappearing into nowhere by extinction This extinction is to be distinguished from the dispersal of galaxies due to universal recession By a blend of the twin ideas of continuous creation and continuous extinction he claimed that gravitation was not the "signature tune of matter" as supposed by tradition but only its "swan song" at the moment of its extinction The recent discovery of quasi-stars has sparked a number of novel ideas like Wheeler's suggestion that matter might literally obliterate itself out of existence by gravitational collapse within what is known as Schwarzchild limit The idea is not as fantastic as it may look at first sight For it is a concept inherent in Einstein's general relativity as the German astronomer Karl Schwarzchild showed over forty years ago He proved that the local curvature of space which is dependent on the mass of the matter in its immediate vicinity can ultimately close around itself and isolate its contents from the rest of the universe This is a way of saying that a sufficiently massive body will prevent the escape of even light or radio quanta (signals) so that it can no longer be observed by anyone outside itself as effectively as the earth does that of projectiles fired upwards with velocities below 7 miles per second But to do so the body has to be very dense For example for the sun to escape observation by trapping within itself the emission of all light or radio signals, it will have to shrink its existing radius of 7×10^5 km to only three This ultimate radius of self-effacement of a massive body of mass M, the so-called Schwarzchild limit, is given by the expression $2GM/c^2$, where G and c are respectively the gravitational constant and velocity of light It can be shown that when a massive body of mass M contracts to its Schwarzchild limit, it will prevent the escape of any light ray or radio beam from itself so that it simply disappears from view of any outside observer In the process of its gravitational collapse within the Schwarzchild limit, it releases half its total energy $E=Mc^2$ locked within it This process is about

100 times more efficient than any thermonuclear reaction. It has, therefore, been suggested that in quasars we may be witnessing an early stage in the evolution of the universe that occurred soon after the explosion of the primeval atom 17 billion years ago. If so, their existence is a refutation of the steady state theory.

In spite of their radical difference both the big bang as well as steady state theories have a somewhat common approach to the genesis of galaxies. As we saw, the fragmented primeval atom became after the expiry of the reign of radiation a dispersed mass of extremely tenuous gas of hydrogen atoms. Likewise, according to the steady state theory, the intergalactic space too is sprouting from nowhere hydrogen atoms at a rate just sufficient to compensate for the dispersal of extant galaxies due to recession. Calculation shows this rate to be 0.3 hydrogen atoms per cubic kilometre per century. Although it is a rate too low to be directly detectable by any observation we may make, even such a low rate of generation spread over the vast intergalactic spaces would provide in course of time sufficient material for the emergence of galaxies. In either case we are led to a more or less similar state of extreme tenuity, a few atoms of hydrogen per 1000 litres of volume in the cosmic space.

It seems that our universe of stars and galaxies was formed out of such an extreme tenuity largely under the influence of three main forces, gravitation, turbulence and magnetohydrodynamics. Unfortunately our knowledge of the laws of cosmic turbulence as well as magnetohydrodynamics, that is, behaviour of conducting gases in magnetic fields in cosmic space is too meagre to give any great insight into a situation that is vastly complicated. But, if we simplify our problem by ignoring the effects due to magnetohydrodynamics and turbulence, we may remark that gravitation as the leit-motif of the origin of the worlds is almost as old a theme as the law of gravitation itself. Newton himself used it to explain the origin of the sun and fixed stars when he suggested that "matter evenly distributed through infinite space could never convene into one mass (but) into an infinite number of great masses scattered at great distances from one another." Indeed, it can be shown that such an extended homogeneous gaseous medium not only splinters off into a series of distinct accretions around separate nuclei instead of coalescing into one huge central mass but that this is merely the first stage of its break-up. For each separate accretion, the denser first-generation subclouds of the original parent cloud, in turn fragment into a series of second-generation subclouds, and so on. Thus each successive generation of subclouds of gas shrinks as a whole until it is dense enough to cease further shrinkage. It is then ripe to begin fragmenting into a number of next generation subclouds. One may imagine this process of condensation and fragmentation as continuing indefinitely. But a state ultimately arrives when two new factors emerge to break the chain.

First, a system formed in the way described would inevitably start rotating as a result of the intermingling of currents in the original gas, just as whirlwinds arise when currents of wind collide But any rotation that the system might acquire initially would tend to increase continually with further shrinkage, as that is how the system can conserve its angular momentum It is this conservation law that is used when a skater whirling about with extended arms manages to spin faster by pulling in his arms The increase in rotation would increase the centrifugal force until it became large enough to balance the gravitational attraction

Broadly speaking, two courses of evolution are then possible If the system happened to start with low initial rotation, the condensation process would last longer, for it would take longer for shrinkage to increase rotation sufficiently to provide enough centrifugal force in the plane of rotation to balance gravitational attraction As a result, it would contract far more in the plane of rotation so that it very likely would become extremely dense and condense almost completely into stars forming a closely compacted system such as an elliptical galaxy A faster initial rotation, on the other hand, would severely limit its contraction in the plane of rotation because centrifugal force sufficient to balance the gravitational attraction would now be built up sooner Consequently, the contraction in this plane would cease much earlier than contraction in the perpendicular plane Such a system would, therefore, evolve into a loose, disc-shaped galaxy with a great deal of uncondensed gas especially in its outer parts, which is what we call a spiral galaxy

The second cut off process limiting the condensation of the subcloud arises from the fact that condensation of any material by its self-gravitation releases energy in much the same way as a falling cascade of water generates hydroelectric power A part of the gravitational energy released by the shrinkage of the subclouds is lost by radiation as heat But how much of it is lost in this way depends on the radiation capacity of atomic hydrogen, which varies widely with its temperature At temperatures below 10,000°C it is negligible, but it mounts sharply when the temperature rises beyond this level, and particularly when it exceeds the one million mark

Now calculation of the supplies of gravitational energy likely to be available as a result of the condensation of subclouds of the dimensions under review shows that the gas temperature inside them is unlikely to be below 10,000° or more than 1,000,000°C Between these two rather wide limits all ranges are not equally probable There are reasons to believe that the most likely temperature ranges are (i) between 10,000° and 25,000°C and (ii) between 150,000° and 1,000,000°C

At the lower temperature range practically none of the gravitational energy released by possible shrinkage is radiated as heat if a cloud contains a mass significantly in excess of 10 billion suns Consequently, all of it remains stored in the subcloud This means that

the cloud cannot shrink further as a whole because even if it did shrink a bit, the stored gravitational energy would merely re-expand it to its initial dimensions, though perhaps in a different direction Therefore, it fragments into a number of small subclouds When the subcloud at last attains a mass of the order of 10 billion suns, which is the average galactic mass, about half the gravitational energy released by its shrinkage is radiated as heat This continues until the cloud shrinks to about one-third of its original size, which on the average is roughly 100 000 light years across It is now too dense to shrink further as a whole and thus begins to yield its own progeny of subcloud The further fragmentation of the subclouds proceeds at an ever-accelerated pace until they become so dense and opaque that they cannot lose any more heat by radiation As a result the fragmented subclouds can break up no further and become embryo population II stars When this happens, the primeval galactic cloud begins to burst into myriad stars

It is in this way that gravity conjures the star-spangled heavens out of the Cimmerian darkness of the deep Hoyle finds a corroboration of this theory in the mass range of population II stars which is observed to lie between 0 3 and 1 5 times that of the sun For, according to his calculation, when gravity has herded material to this extent, it becomes so opaque as to stop losing any heat by radiation and thus ceases to fragment further

Once the galactic mass has broken up into a loose system of stars in the manner described, mere passage of time suffices to compact it into a condensed system similar to what we find in the elliptical as well as in the central cores of spiral galaxies Although most of the stars of the system cluster by mutual encounters into a central amorphous mass, some do remain at the outer periphery of the parent subcloud where they were born These remaining stars are the very extensive halos surrounding the galaxies

We have now to consider the higher temperature range mentioned above It has been estimated that for a gas cloud to increase its internal temperature to the million mark, its total mass must exceed 10,000 billion suns, that is about 1000 times the average mass of a galaxy spread within a sphere of about 6 to 7 million light years in diameter *A cloud of these dimensions begins by contracting as a whole until it develops a temperature* of one million degrees At this temperature heat losses by radiation leap up suddenly to a prodigious level, leading to a sudden fall of temperature The outcome of this cataclysm, a temperature surge of about a million degrees, is a shower of thousands of dwarf protogalaxies with an average mass of only 300 million suns Each protogalaxy is then well on its way to becoming a galaxy by further fragmentation into stars in the manner already described

However, a close cluster of 30,000 dwarf galaxies cannot remain in the state of loose anarchy in which it is born A war of consolidation ensues Some of the closer

dwarfs coalesce and become powerful enough to devour others. As always, the big become bigger until a few giants emerge by the consolidation of some two to three hundred dwarfs. It is in some such ways that the giants like Andromeda and our own Milky Way in the Local Group were built up.

CHAPTER TWO

STELLAR EVOLUTION

WE HAVE already seen how the homogeneous primeval cloud of hydrogen due to its gravitational instability coupled with its proneness to turbulent motion broke up into a multitude of distinct clusters of protogalaxies. They must have continued to recede from one another while each cluster was left to proceed with its own evolution. We also saw how during the course of this evolution the original gaseous material of the protogalaxy in turn broke into myriads of shining stars. The details of those processes which led to the transformation of cool dark gaseous protogalaxies into the star-spangled heavens of today are still not fully known. But it seems that the galactic material first condensed into a multitude of distinct embryo stars That is, each embryo became a small opaque globule of gas that was too dense to break up any further. In consequence, it began to contract under its self-gravitation with gradual rise in its temperature. The period of contraction before its temperature became large enough to make it luminous depends on the mass of the embryo or protostar. Table 1 gives the duration of the gravitational contraction phase with reference to the mass before its emergence as a luminous star.

The initial mass of the protostar also decides at what point in the Hertzsprung-Russell (H-R) diagram it will begin its life as a star. H-R diagram, by the way, is a graphical representation of the two most important attributes of stars, viz. their luminosity and surface temperature Thus, if we denote a star by means of a dot on graph paper whose ordinate is its absolute magnitude, and abscissa its spectral class or what amounts to the same thing as its surface temperature, we obtain a scatter of points as shown in Fig. 5. A glance at it shows that majority of the dots cluster around one main line PQ. But there are plenty of exceptions concentrated towards

TABLE 1

MASS OF THE PROTOSTAR	DURATION OF GRAVITATIONAL CONTRACTION
20 suns	3×10^4 years
3 suns	2×10^6 years
1 sun	5×10^7 years
6 suns	2×10^8 years
2 suns	10^9 years

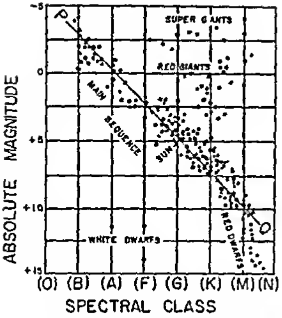


FIG. 5 H R DIAGRAM (From Jagjit Singh 1961 Dover Publications, New York)

the top right of the diagram This does not mean that the left hand exceptions are few even though our diagram shows only three, they happen to be too faint to be seen unless they are very close to us The exceptions to the right are known as red giants because they are so luminous and large that they could easily accommodate within their bosom the whole of our terrestrial orbit, including the sun, Mercury, Venus and earth, and yet have room to spare In spite of their bulk they are practically hollow inside In fact, they are so diffuse that their density is lower than that of a good terrestrial vacuum

In the opposite camp are the three left deviationists located towards the lower left corner of our diagram Because of their small luminosity and high surface temperature, they are called the white dwarfs They are packed to the brim with material, a matchbox of which would easily weigh several tons A case in point is the companion of Sirius

These left deviationists are said to be in a "degenerate" state This is a technical term devised by astrophysicists to denote a peculiar condition of matter in its last stage of condensation When we compress anything, say, an ordinary gas, we soon reach the limit of its compression because its atoms refuse to interpenetrate one another no matter how hard we press it But what cannot be done on earth is not too difficult inside stars For at pressures and temperatures such as prevail there, the atoms are stripped bare of their electrons and a good deal of interpenetration takes place. But in the white dwarfs even the separate identities of individual atomic nuclei are destroyed by further pressure

and the nuclei and electrons are packed cheek by jowl so that they cannot come any closer Such a gas is said to be degenerate Degenerate matter, therefore, is the ultima thule of condensation Or, rather penultima now that matter inside the recently discovered quasars is believed to be in an even denser state of condensation That is why the estimate of its density quoted above several tons per cubic inch is no Munchausen story. It is the outcome of one of the most precise calculations modern science can make. That is also why the stuff of which white dwarfs are made has its own peculiar laws and its peculiar appellation Even energy transport in its interior takes place neither by radiation nor by convection but by conduction, as in a metallic bar with one end in a firebox

It is now believed that an average star begins its life as a main-sequence star and ends it as a white dwarf if it does not in the meanwhile blow itself to pieces as a supernova Immediately after its emergence as a self-luminous star from a self-gravitating globule of gas it appears somewhere on the main-sequence, its mass determining its initial position on the main-sequence line It remains for a while in this state of what is called radiative or convective equilibrium This merely means that the star maintains itself in a steady state without having to shrink or expand, as the outflow of radiation from its outer surface keeps pace with energy generation in its interior by nuclear transformation of hydrogen into helium

These nuclear transformations are of two main types In the case of stars with masses equal to and lower than that of our own sun, the energy they radiate is derived from the proton-proton reaction, which leads to the building of helium nuclei through direct interaction between protons with the consequent mass-loss released in the form of nuclear energy In stars with masses in excess of three solar masses the carbon nuclei act as catalysts to produce the same net result of transforming protons into helium nuclei In stars with masses intermediate between that of the sun and three times as great, both processes may operate simultaneously, the carbon cycle in the central parts and proton-proton reaction in the outer shells surrounding the stars' interior core In either case the star remains in its stable main-sequence stage for a period of time which may last from a few million years in the case of very massive stars to a few billion years in the case of light ones Table 2 gives the duration of the stable main-sequence stage for a few typical values of stellar masses

Although these time intervals are very uncertain, they are all about 100 to 1000 times longer than the first stage of gravitational contraction shown in Table 1 But in both stages of its life, viz. as a contracting globule of gas and as a main-sequence star, the more massive the star, the briefer its life span

Whatever its life span as a main-sequence star, a star usually remains in this steady

TABLE 2

Stellar mass	Duration of main sequence stage
20 suns	10^7 years
3 suns	5×10^8 years
1 sun	10^{10} years
0 6 sun	10^{11} years
0 2 sun	10^{12} years

state of equilibrium for only about 5 to 10 per cent of its total life Why? Because as it burns its hydrogen in the hottest central regions, a core of helium ash is deposited at the centre and gradually grows in size When it accumulates to about 10 per cent of the mass of the star, its configuration ceases to be stable For the core shrinks and the gravitational energy which the shrinkage releases heats it up, while the outer envelope of the star expands enormously But the enormous distention of the outer envelope cools it so that it begins to radiate cooler, that is, redder light In other words, the star now becomes a red giant According to this theory, our sun will become a red giant one day Then as it grows in size, it will begin to swallow the planets one by one, commencing with Mercury and ending with our own earth or even Mars If so, the Koranic vision of a doomsday when the sun will grill the earth from a distance of a spear and a half might come true unless we choose to advance it by some 5000 million years by the massed ignition of a sufficient number of those miniature suns, the H-bombs

This outline of the course of stellar evolution is no mere mathematical fantasy We may actually see it in progress on the vault of the heavens For we find in our galaxy confederations of stars whose close association in the group shows that they are all of the same age, even though one group as a whole may be older or younger than another If we show in our H-R diagram, the stellar populations of these groups, such as the young double cluster in Perseus and the middle-aged Pleiades, we find that while the stars of both the systems congregate around the main-sequence towards the lower right-hand end of the diagram, the distribution of the stars in the upper half of the diagram is widely different for the two groups (Fig 6) These upper-end deviations from the standard main-sequence are in conformity with the theoretical evolutionary tracks predicted by Schonberg-Chandrasekhar stellar models

The diagram also shows that some super giants of the Perseus cluster are far away from the main-sequence Their location too agrees with the synthetic evolutionary tracks yielded by Sandage-Schwarzchild stellar models What is true of these two clusters has more recently been verified for nine more clusters Fig 7 exhibits similar evolutionary

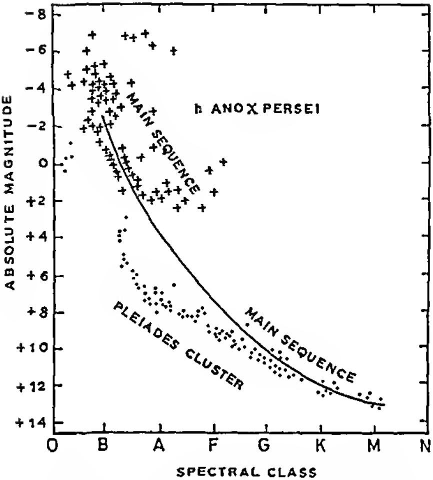


FIG. 6. LUMINOSITY AND SPECTRAL CLASS DIAGRAM FOR THE NUCLEAR REGIONS h AND χ PERSEI AS WELL AS PLEIADES The solid line is the standard main-sequence (From Jagjit Singh, 1961 Dover Publications New York)

differences between the stars of ten galactic clusters and one globular cluster including Perseus and Pleiades in a schematic form. The dotted lines in the diagram are the fate lines of each cluster charted by stellar horoscopes. The actual scatter of stars of each system in close proximity to its own fate line is a confirmation of the theory of stellar evolution outlined above.

But to revert to our community of evolving stars, it seems that stellar communities are like monolithic societies, in that a star merely buys trouble for itself by venturing to stray into right deviationism, alias red giantism For a red giant runs into a veritable storm of catastrophes, cataclysms, and crises in an endeavour to balance its energy budget, which is repeatedly upset by happenings in its interior. What happens there is this the hot helium core inside, at a computed temperature of *100 million degrees, becomes a*

cosmic witch's cauldron brewing atomic nuclei of lighter elements such as carbon, oxygen, neon, and possibly even magnesium from those of helium Although even after deviating from the main-sequence, the bulk of the star still consists of hydrogen and the bulk of the energy production still flows from the hydrogen-helium conversion in a thin shell outside the core, the atomic consolidation now under way in the core also contributes its share of nuclear energy in the core to keep it at its temperature of 100 million degrees

As the core continues to contract and the temperature exceeds 100 million degrees, the alpha particles (that is, the helium nuclei) interact with the neon nuclei to form magnesium, and then with these nuclei in turn to form the ordinary isotopic forms of the nuclei of all the elements up to iron whose atomic weights are multiples of 4 After all the helium has thus been used up, the core will begin to contract again with a release of gravitational energy, and this new contraction will spark the core temperature to still dizzier heights, some 1 to 2 billion degrees, so that the cosmic witch's cauldron now becomes a cosmic synchrotron It triggers interactions among the heavier nuclei themselves

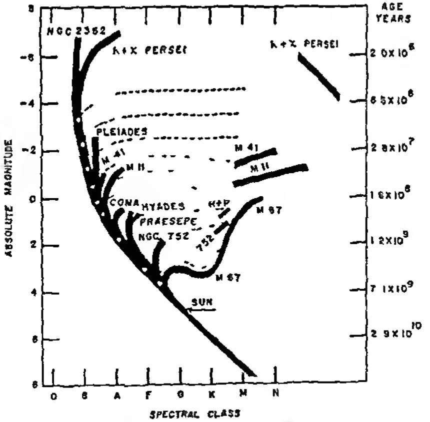
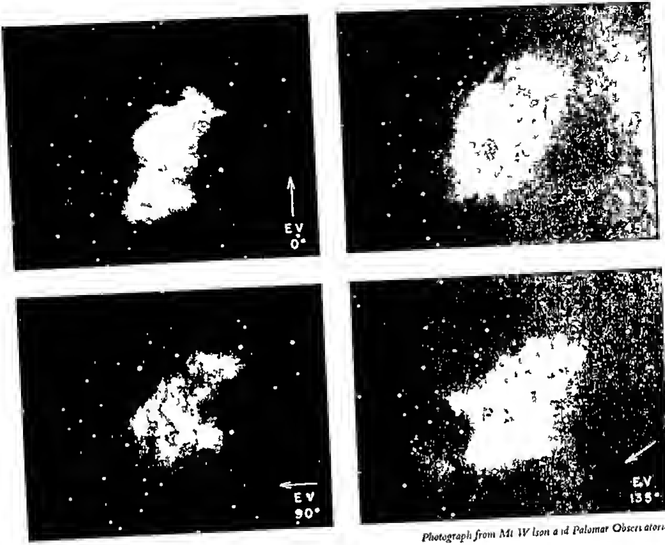


FIG 7 LUMINOSITY SPECTRAL CLASS DIAGRAM (From Jagjit Singh 1961 Dover Publications New York)

These are of two main kinds depending on the type of star. For according to present day theories of stellar evolution the stars that we see in our own Milky Way as also those in other galaxies evolved in two distinct stages corresponding to the two distinct types of stars populating them. Thus, the stars of our own Milky Way exhibited in the usual H-R diagram, that is, stars in the region near the sun are known as population I, and are quite different from those of population II located in its more distant central regions. Because population II stars are believed to have been formed earlier probably all at the same time at a fairly early stage of cosmic evolution, when the primordial gas clouds from which they condensed had relatively greater abundance of hydrogen, they contain a very small amount of helium, and other heavy elements like carbon, nitrogen, oxygen, etc. all of which are grouped by astrophysicists under the omnibus title "metals". Population I stars like our own sun, on the other hand, seem to be second-generation stars which were formed later. For they have considerable amount of heavy-element abundance thus indicating that they condensed out of hydrogen clouds that were impregnated with greater quantities of "metals" forged in the interiors of massive population II stars which are presumed to have since blown themselves away in supernova explosions. It is also very likely that the heavier elements were spewed out by them in periodic outbursts before their final extinction. In any case population I and II categories of stars have condensed out of two distinct types of hydrogen clouds — population I having arisen from those more richly impregnated with metals than population II and therefore, comparatively younger source material than the comparatively purer primeval hydrogen cloud.

In the case of population II stars, formed out of primeval hydrogen clouds the nuclear reactions triggered in its core towards the end of its red giant stage produce heavier nuclei such as carbon, oxygen, neon, to produce additional quantities of multiple-4 type nuclei right up to iron-56. In the case of population I stars, which are, however, formed out of not so pure hydrogen cloud but out of material containing small proportions of the multiple-4 type nuclei (such as carbon-12, oxygen-16, and so forth), the interactions of these nuclei with the protons give rise to the nuclei that are not multiples of 4 (such as nitrogen-14, sodium-23, and so on).

However, to continue the story of evolving population II stars, the game of nuclear consolidation comes to an end with the emergence of iron-56 by nuclear transmutation in the core. For any further nuclear consolidation, involving the iron group of elements, absorbs energy instead of releasing it. Consequently these nuclei cannot serve as nuclear fuel to continue the chain of fusions. The elements heavier than iron, however, will be built up by two different processes of neutron capture. Since many isotopes of the different nuclei will be formed by proton capture, in which there will be one neutron more than the number of protons in these nuclei, large fluxes of neutrons will be released when



Photograph from Mt Wilson and Palomar Observatories

THE CRAB NEBULA IN TAURUS

these isotopes react with alpha particles Thus the interaction of helium with neon of atomic weight 21 will lead to the formation of magnesium of atomic weight 24 and the release of a neutron This neutron, and others like it, will then be available for capture by iron resulting in the formation of nuclei heavier than iron Indeed, the complete series of the very heaviest nuclei will thus be built up Another source of neutrons leading to the rapid buildup of heavy isotopes beyond uranium is found in the explosions of supernovae That such heavy elements can indeed be built up in this way was demonstrated by the first explosion of a hydrogen bomb at Bikini The neutrons released during this explosion were captured by nuclei in the metallic shell of the bomb and transformed these nuclei to transuranium elements such as californium-254, and the like

Because these trans-iron nuclear transmutations now proceeding inside the star absorb energy instead of releasing it, the star passes from the regime of nuclear-energy sources to that of gravitational contraction It can be shown that such a transitional stage is unstable This instability manifests itself in a variety of ways depending on conditions not yet fully understood For example, the star may be thrown into violent but rhythmic pulsations of its spherical surface, causing periodic changes in its luminosity like that we actually observe in variable stars like RR Lyrae or the Cepheids Having passed through this condition of periodic pulsations a stage at long last arrives when the star becomes so unstable that it begins to shed mass either gradually or catastrophically from its outer layers The reason for this is that with continual compression the core becomes compressed to the ultimate limit of degeneracy Once degeneracy sets in new factors come into play A calculation by Chandrasekhar has shown that under these conditions there is an upper limit beyond which the core mass cannot grow This limit is 1 4 times the mass of the sun Consequently a massive star with, say, fifteen to twenty times the solar mass has to lose considerable quantities of matter once it has burnt about 7 to 10 per cent of its hydrogen which would bring the mass of its helium core close to the Chandrasekhar limit The outer envelope then becomes a Nessus' shirt on our Herculean star The star must wrench and tear off whole pieces of this garment in a violent fit of self-dismemberment until it is completely consumed In astrophysical language the star explodes catastrophically, becoming a supernova, that is a nova which shines for a brief while with 200 million times the solar luminosity

We have observational evidence of such happenings For instance, the Crab Nebula (Pl 5) in the constellation of the Bull is the debris of such a catastrophic explosion of a star in our own galaxy in the year 1054 when the "guest-star', as the Chinese who recorded its observation called it flared into such phenomenal brilliance that it outshone every other star in the sky and for three weeks on end was visible even to the naked eye in broad daylight In our own day similar supernova explosions in other galaxies

regularly occur but require special techniques for their observation because of their vast distances from us For, however great may be the enchantment distance lends here on earth up in the heavens it only dims the view

Such colossal catastrophes as supernova explosions are rare because of the rarity of massive stars although they might have been more frequent in the earlier stages of our evolving universe It has even been suggested that in quasars we may well be witnessing now an almost simultaneous explosion of most of the stars in a remote galaxy that occurred some billion years ago Be that as it may, while major celestial upheavals like supernova explosions are rare at present, comparatively minor explosions are more frequent For even an average star, with a mass only a few times that of the sun, sooner or later has to shed matter when hydrogen burning has proceeded far enough for the helium core to approach the Chandrasekhar limit. But as the excess mass required to be lost in these cases is much less than with the massive stars, the loss is not catastrophic. The star bursts into a nova, that is, increases its brightness 30 to 100 000-fold, possibly not once but several times ejecting the extraneous material which the core can no longer absorb About twenty to thirty nova explosions are observed to occur every year in the Milky Way, and there is reason to believe that fits of novatitis are likely to recur, as a number of repetitive novae have been discovered

At long last in the course of repeated outbursts the aging nova gradually evolves, with one exception into a typical white dwarf, having ended its career of violent vicissitudes of distentions, pulsations, ejections, and explosions The exception is in the rare case when the star detonates as a cosmic "helium bomb", blowing itself to pieces as in a supernova explosion Whether such an explosion leaves a relic of the parent star or completely obliterates the star from existence is still in doubt There is some evidence to show that in many cases a relic star remains at the core of what is observed as a planetary nebula If so, the formation of a planetary nebula is yet another way in which a star manifests its instability which, though analogous to that of a nova or supernova outburst, many have no direct connection with either

In any case, an aging star, if it manages to avoid blowing itself up as a supernova, does pass into quiescence as a white dwarf after some recurrent fits of novatitis Nothing very spectacular can happen to it now For it has practically no wherewithals of energy left, either nuclear fusion or gravitational, because as a white dwarf it contains very little hydrogen in its interior, has too low a temperature for nuclear reactions involving helium or heavier nuclei, and is too dense to contract any more, being all degenerate electron gas. With all its energy engines shut, it can do nothing but free-wheel gradually into the oblivion of a dark invisible star.

CHAPTER THREE

THE ORIGIN OF THE SOLAR SYSTEM

OUR SOLAR SYSTEM consists of the sun, nine large planets, 1600 asteroids and an indefinite number of comets and meteors, all voyaging together as one dynamical ensemble in interstellar space. Any theory of its origin must explain the following four main features of the system.

(a) First, there are the orbital regularities, which means that all the planets revolve around the sun in more or less the same plane in nearly circular orbits and in the same direction. The rotation of the planets around their axes (as well as the sun's own axial spin) also follows the same direction as their orbital revolutions. Moreover, the planetary orbits lie almost in the equatorial plane of the sun if we ignore the small inclination between the two—only about 6°.

(b) Secondly, all the planets are situated at regular distances from the sun. If we adopt the earth's distance from the sun as our unit of reckoning, the distance r_n of the nth planet from the sun conforms quite closely to the so-called Titius-Bode law except in the case of the last two planets, Neptune and Pluto.

$$r_n = 0.4 + 0.3\ (2)^{n-1}$$

Fig. 8 is a schematic representation of the nine planets and the asteroids of the solar system showing their actual distances alongside the corresponding distances according to Bode's law. It is perhaps no mere accident that planetary distances follow Bode's law. For there is some evidence to show that it holds to some extent even in the case of distances of the satellites from their respective primaries also.

(c) Thirdly, while the masses of the four inner planets are low and their densities high, masses of the four outer or Jovian planets are high and densities low (Fig. 8).

(d) Fourthly, almost the entire rotation of the system, as measured by its angular momentum, is packed into the planets and their satellites, whereas the entire mass of the system is concentrated in the central sun. The sun possesses over 99 per cent of the mass of the system but barely 2 per cent of its total spin or angular momentum. For this reason, slow evolutionary cosmogonies like the nebular hypothesis of Kant and Laplace have been found to be untenable even though the recent invocation of new effects due to magnetohydrodynamics and turbulence have made them somewhat more plausible.

NOT TO SCALE

Density (in grams per cm^3)	Mass (in Earth's mass as unit)	Bode's law	Distance (in astronomical units) actual	
				SUN
4 5	05	4	39	MERCURY
4 8	8	7	72	VENUS
5 5	1 0	1 0	1 0	EARTH
3 9	1	1 6	1 52	MARS
		2 8	2 805	ASTEROIDS
1 3	318 0	5 2	5 2	JUPITER
7	95 0	10 0	9 5	SATURN
1 5	14 6	19 6	19 1	URANUS
2 4	17 2	38 8	30 0	NEPTUNE
53 (?)	9	77 2	39 4	PLUTO

Fig 8 Solar system (From Jagjit Singh 1961 Dover Publications New York)

Among the many theories of the origin of the solar system that have been proposed in the past, the basic ideas of Schmidt and Urey are the most likely to succeed According to Schmidt the origin of the planets came about because the sun on its journey around the centre of the Milky Way passed through a cloud of gas and solid dust particles, a part of which it somehow managed to drag in its wake Since the cloud, like the sun itself, was initially rotating around the galactic centre, its capture turned part of its rotation around the sun, thus flattening the cloud At the same time, the dust particles separated from the gas by solar radiation, began to precipitate towards the central or equatorial plane of the flattened cloud (Fig 9) In this collection of dust specks into a flat disc, the mutual gravitational attraction between the particles increased because of the smaller separation The result was the agglomeration of the small primordial particles of the dispersed protoplanetary material into a multitude of asteroidal bodies of different size and mass, that is, bodies of size intermediate between the primordial particles and the present planets Some of the larger asteroidal bodies which grew faster than others became the "embryos" of the planets, budding in time into full-fledged planets by gradual accretion of the remaining asteroidal bodies and their fragments (Fig 9)

Schmidt's collaborators — Gurevich, Lebedinsky, Levin, and others have employed

the methods of statistical physics to show that a system of solid particles with greater angular momentum and sufficient total mass must inevitably follow the evolutionary sequence briefly outlined above. In this way Schmidt has no difficulty in explaining feature (a) — the orbital regularities of the solar system. Nor is feature (d) — the peculiar distribution of angular momentum much of a hurdle. For in Schmidt's theory, the angular momentum of the cloud and hence of the planets is not directly connected with that of the sun. It is derived from the angular momentum pertaining to the rotation of the stars and the interstellar gas and dust clouds around the centre of the galaxy. By thus relying on the virtually inexhaustible total store of the angular momentum of the entire galaxy as a source of supply of the planetary angular momentum, Schmidt has no need to invoke any hypothetical physical laws to endow the planets with the lion's share of the angular momentum of the solar system which they actually possess

For his explanation of feature (b) Schmidt considers that when planets are being formed, those particles have the greatest chance of joining the "embryo" planet whose specific angular momentum (i.e. angular momentum per unit mass) is closest to that

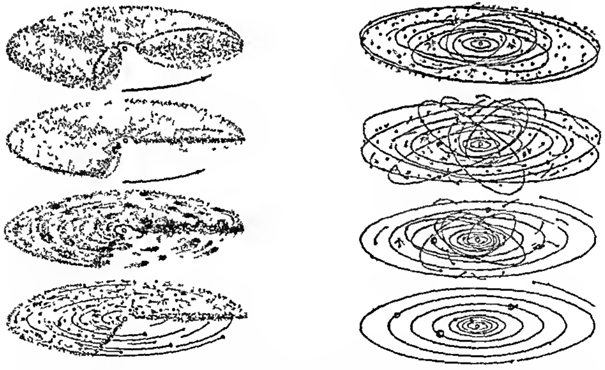


FIG 9. TWO STAGES IN THE EVOLUTION OF THE PROTOPLANETARY CLOUD ACCORDING TO SCHMIDT *Left, the cloud flattens into a disc on account of its rotation and the solid primordial particles separated from gas agglutinate into a swarm of asteroidal bodies Right, the swarm of asteroidal bodies thickens through mutual collisions and leads to planet formation by their gradual accretion* (From Jagjit Singh, 1961. Dover Publications, New York)

PICTURE OF THE LUNAR SURFACE BY SOVIET ZOND III TAKEN ON JULY 20, 1965

of the embryo Schmidt concedes that some particles, of course, may join an embryo planet other than their "own" but such deviations would mutually cancel themselves out, so that the particles may be assumed to be distributed along the sections of the axis of specific angular momentum allotted to each embryo Since a particle's specific angular momentum is proportional to the squareroot of its orbital radius, Schmidt is able to prove that on the assumption of a smooth distribution of matter in the protoplanetary cloud, the angular momenta of the planets and in consequence the squareroots of their orbital radii would increase approximately in arithmetical progression In other words, the orbital radius R_n of the nth planet would obey the following relation

$$\sqrt{R_n} = p + qn$$

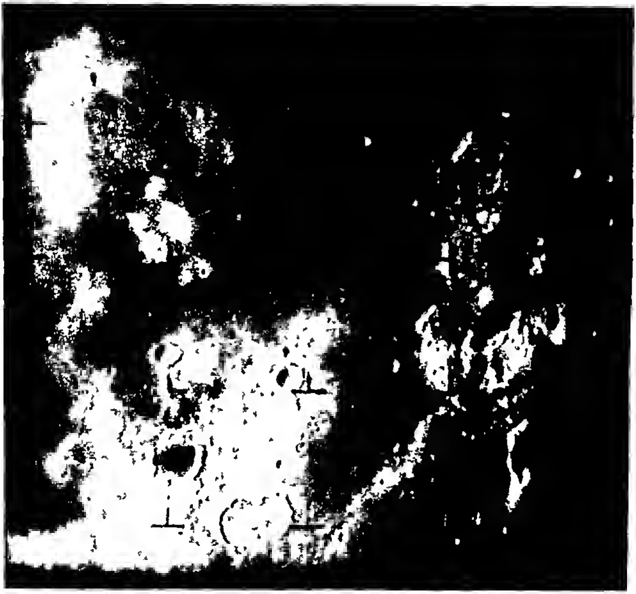
wherein p and q are constants

But to secure agreement between the formula so derived and the actual values of the planetary orbital radii he is obliged to assign one set of values to the constants p and q for the group of four inner planets and quite another for the five outer planets This may look arbitrary, but the division of planets into two groups of four inner or terrestrial and five outer or giant planets reflects the difference in the properties of the inner and outer zones of the protoplanetary material For, it can be shown that up to a distance coinciding with the asteroid belt the sun's heat is appreciable, but beyond it quite close to absolute zero As a result, in the small inner zone of the terrestrial planets warmed by solar heat, only particles of nonfusible stony matter and metals with high density could survive the solar heat stroke. In the huge outer zone of the giant planets sheltered from the sun's radiation by its greater distance, the temperature of the particles was so low that volatile substances froze onto them—water vapour, carbon dioxide, methane, ammonia, and related compounds In this way Schmidt not only justifies his choice of two different values of the parameters p and q in the distance law given above, but also provides a natural explanation of feature (c) of the solar system, that of high density and low mass of the inner-terrestrial planets and low density and high mass of the outer giants

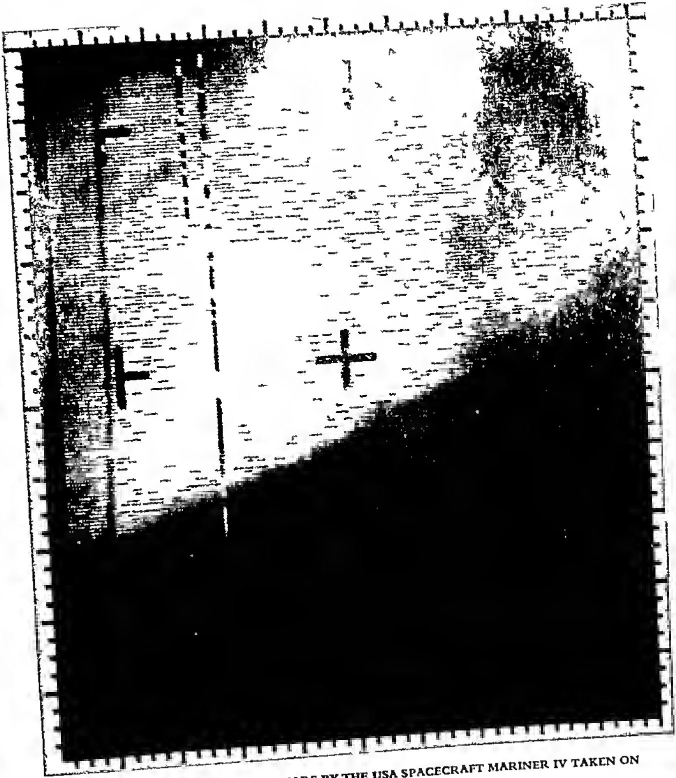
Schmidt's cosmogony thus provides a fairly plausible explanation of all the four main regularities of the solar system An additional merit is its emphasis on the accumulation of solids from smaller-size primordial particles after their separation from gas by solar radiation, a feature that is in better accord with present day geochemical research Such research provides valuable complementary clues to the solution of the cosmogonic riddle in that by considering the present composition of the earth's crust, its mantle of water and atmosphere, we can visualize some of the earlier stages of our earth's evolution on a basis independent of remote cosmological origins

PICTURE OF THE LUNAR SURFACE BY SOVIET ZOND III TAKEN ON JULY 20, 1965

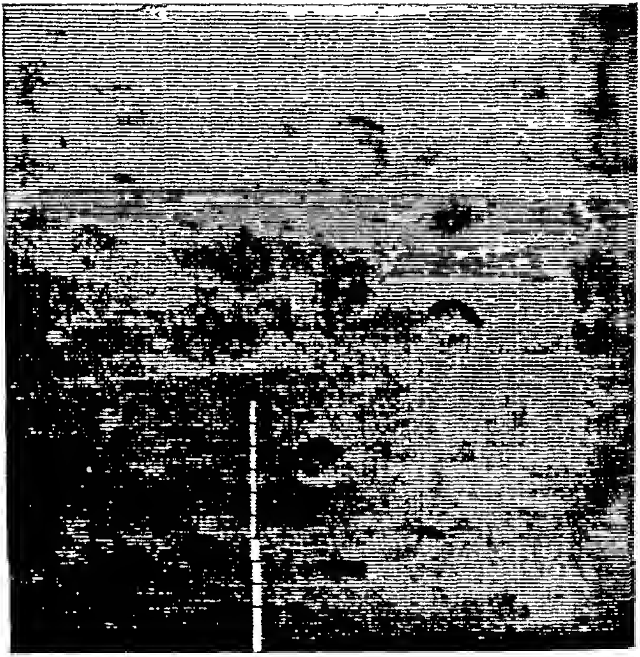
Pl. 7



LUNAR PHOTOGRAPH TAKEN BY USA RANGER VII SPACECRAFT ON JULY 31, 1965



PHOTOGRAPH OF SURFACE OF MARS BY THE USA SPACECRAFT MARINER IV TAKEN ON JULY 14 1965



PHOTOGRAPH OF SURFACE OF MARS BY THE USA SPACECRAFT MARINER IV TAKEN ON JULY 14, 1965

Thus in 1953 the celebrated geochemist, Harold C Urey, showed by a study of the present abundance of relatively volatile elements, such as mercury and boron on the earth's surface that it was unlikely to have ever been exposed locally to temperatures of more than a few hundred degrees centigrade and may not even have been hotter than the boiling point of water* Further, a hot molten earth, in its early accumulative stage, could never have produced the earth we know today but only an arid, oceanless planet For molten materials could never hold any interior water to be released later on cooling Urey reinforced this conclusion by his study of other planets like Mars, whose equatorial bulge was shown to be inconsistent with a core-mantle structure It is best accounted for by assuming that about 30 per cent of the planet is iron distributed uniformly throughout the rocky globe Such a condition could never have come to pass if Mars had ever been molten These and other recent observations of Urey seem to favour Schmidt's fundamental assumption that planets were formed by the accumulation of primordial dust at relatively low temperatures Indeed, Struve's recent discovery of a region about Sco B, where there is no hydrogen but iron and presumably other non-volatile elements, is in agreement with this Here at any rate there is evidence that a separation of the type Schmidt envisages is a cosmic possibility, having occurred at least somewhere For these reasons Schmidt's theory is the most plausible cosmogony we have so far, even though its inability to specify an acceptable mechanism, whereby the sun could capture a dust-gas cloud is still an unresolved difficulty

There are, no doubt, many other cosmogonies notably those due to Kuiper, Weizsker, Alfven, Whipple and others But observation has not yet been able to decide conclusively between them The difficulty will most probably be resolved in the near future by the new techniques of space research now being employed For example, the mysterious surface of the moon most probably contains a record of the history of the solar system, a record that has long ago been obliterated on earth through the violence of geologic processes here We should be able to read it when instruments and people are landed on the lunar surface Likewise, new information found from the surface of Mars and Venus when these come under direct investigation by instruments landed there should provide even more valuable clues concerning the origin of the solar system Already a beginning

*The high temperatures of a few thousand degrees centigrade that are known to prevail now in the earth's interior and the existence of a core of molten iron beneath the mantle of rock at one time led to the belief that the earth had passed an earlier molten stage We now know that this internal heating is the outcome of the slow accumulation of heat released through the breakdown of radioactive elements a small admixture of which forms part of earth's substance Since the rate of heat generation is known precise calculation confirms that thermal energy generated by such radioactive disintegration accumulated over long periods of a few billion years of the earth's existence is sufficient to raise its interior temperature to the extent actually observed today

has been made by the Soviet and USA space research programmes which have enabled us to obtain close views of the surfaces of moon and Mars Pl 6 for instance, is a picture of moon's surface obtained on July 20, 1965 by the photo television device of the Soviet automatic interplanetary station Zond III from a distance of only 6000 miles Another photograph of the surface of the moon taken by USA Ranger VII spacecraft on July 31, 1965 is given in Pl 7. It makes it possible to tie confidently the new regions of the moon Similarly, Pl 8 and 9 are photographs of the surface of Mars taken by the USA spacecraft Mariner 4 on July 14, 1965 at distances ranging from 4000 to 6000 miles during a 25-minute sweep across the planet's southern hemisphere The growing body of evidence now being collected in these and other future space probes will no doubt provide firmer basis for speculations concerning the existence of planetary systems orbiting around other stars in the Milky Way and other galaxies beyond For, correct ideas about the origin of the solar system should enable us to confirm our present surmise that many more stars have planetary systems than was envisaged forty years ago when the only way of forming a planetary system was considered to be an exceedingly rare event, viz. a chance encounter of two stars voyaging in interstellar space If our present day theories of planetary origin are even approximately correct, it is very likely that our own Milky Way of some 100 billion stars has hundreds of millions of stars with planetary systems

CHAPTER FOUR

LIFE IN OTHER WORLDS

THE MOLECULAR hurly-burly that heating inevitably lets loose proves too much for the delicately balanced constituents of proteins as well as living tissues. It coagulates proteins, decomposes amino acids, and deactivates enzymes. No living tissue, cell, or bacterium seems to withstand boiling water. The hottest niche that living organisms have so far been known to occupy is in Yellowstone Park, Wyoming, USA, where bacteria have learnt to survive in hot spring at 76°C, but none has been found in any of the hotter natural springs in spite of life's incredible resourcefulness to colonize any possible ecological corner. Apparently 80° to 90°C is a fundamental upper limit to which life can accommodate itself.

The possibility that living organisms made of sterner stuff like silicon in lieu of carbon would be able to survive in a very much hotter environment has no doubt been suggested because silicon ranks next to carbon in its power to combine with other atoms to form a multitude of compounds. But unlike carbon, silicon atoms show little tendency to combine with one another in long chains and rings. This is why the silicon counterpart of the hydrocarbon series does not stretch very far and why even those hydrosilicons which do exist are far more fragile than their carbon prototypes. Consequently silicon is no match for the prolific power of carbon to act as base for the build up of complex structures that are indispensable precursors of life.

Since living matter, wherever it may occur in the universe, presumably requires a vast variety of complex compounds from which to synthesize itself, carbon alone among the elements seems qualified to serve as its backbone. A silicon cell, therefore, is not even a plausible biological "perhaps" so far as we can imagine at present.

But even if it were, it would not materially extend the temperature range up to which life could ascend. For every chemical compound, whether of silicon, carbon, or anything else, can be broken down with sufficient heat. Indeed, the more complex its structure, the more easily it disintegrates. We may, therefore, rule out all possibility of life in any of its variety and adaptations in the stars, as even the coolest of them have surface temperatures of 3000°C, much too high for any except the simplest compounds to exist.

But if excessive heat inhibits life of all kinds, too much cold is equally fatal. For

vital processes, as our experience here on earth shows, depend ultimately on the energy received from the sun If this supply had been much smaller, it is doubtful if life could have ever been sparked out of its inanimate slumber It, therefore, follows that only planets located at just the correct distances from their central star to give them the right amount of starshine and warmth can be suitable abodes of life in any possible form If they are too near their central star, no life can originate in the midst of the hell fires to which their close proximity exposes them On the other hand, if they happen to be too far away, life may remain congealed for ever in the frosty cold of outer space.

But it is not merely their distance from the central star that has to be right. So must be their other features such as mass axial rotation, atmosphere, hydrosphere, ellipticity of orbit, and so on Thus, if a planet or satellite like our own moon fails to combine the right blend of these other conditions, its location at the right distance from the sun will be of no avail. For the moon, having too small a mass to retain any atmosphere, is both airless and waterless Further, since it spins around itself slowly in about a month, a lunar day is as long as a terrestrial fortnight. In consequence, the surface rocks of its equatorial regions are alternately grilled by a fortnight's solar radiation undiluted by atmospheric absorption and are chilled by an equally long Stygian night The noon temperatures at the sub-solar point thus soar to 120°C and drop to −150°C at midnight

Nor is there any wind or water to temper the effect of such violent oscillations of surface temperature In such a lunar chiaroscuro of light and shade, no live organism, even if it could get there somehow, could escape being alternately roasted and put into a deep freeze

Then again if a planet's orbit is highly elliptical, as in the case of Mercury, the seasonal variations in the intensity of solar radiation may prove too great for life to develop and take root Thus Mercury at its closest approach to the sun receives two and a half times as much sunshine as at its farthest This alone gives rise to too violent fluctuations of temperatures but the violence is fantastically amplified because of the coincidence of the period of its axial rotation with that of its revolution round the sun. As a result it presents approximately the same face to the sun as the moon does to the earth, so that it is a fearful furnace of molten lead, lava and tin on the sunny side, and an equally terrifying Cimmerian nightmare of frozen gases on the other, eternally dark, unlit side These conditions, whose rigour is in no way mitigated because of the virtual absence of wind and water, prevent it from harbouring life of any kind whatever

It is therefore small wonder that barely two (excluding our own earth) out of the nine planets and their numerous satellites of our solar system have managed to acquire the right combination of conditions that might provide a possible home for life in some form or other They are Venus and Mars Barring these two, the other planets beyond

Mars are so far off that the punch of the sun rays is attenuated to a mere fraction (4 per cent) of their terrestrial intensity by the time they reach even the closest of them, Jupiter Consequently, Jovian surface temperature is 138°C below the freezing point of water, which is cold enough to liquefy many gases On Jupiter, therefore, and still more on other outer planets beyond, the solar energy, the sole ultimate motive power behind life in any form is much too feeble to lure life out of the dismal frost of these hostile worlds

But even Venus and Mars, in spite of the conjunction of several favourable features, may happen to draw a blank and turn out to be lifeless, leaving only the earth as the sole stage in our solar system for the great epic of life Thus if Venus's axial rotation happens to coincide with its orbital revolution, as some observers seem to have concluded, it will eternally present the same face towards the sun and therefore may have large climatic variations between the sunlit and dark sides although atmospheric currents would tend to equalize things This reduces the probability for life of a high form even though its close resemblance to earth in size and mass, coupled with its possession of a dense atmosphere and extensive hydrosphere, would suggest the probability that it supports life This probability has somewhat improved lately as recent radiometric measurements of the heat emitted by the dark side appear to be too great for it to remain eternally unlit Nor is it whittled down in any way by the circumstances that Venus is perhaps a vast shoreless ocean with practically no land surface at all

Mars would appear to be an arid, waterless desert possibly given to frequent volcanic eruptions with the prevailing winds carrying the dust and ash they raise Under these conditions, life could secure a very precarious foothold, if any, indeed The only indication of Martian life that seems at all admissible for the present is the generally bluish-green colour of the Martian maria (as the dark areas of its surface are called) coupled with the seasonal changes of coloration to which they appear to be subject

It has been suggested that these variations are caused by the seasonal changes in vegetation growing in the maria, though the light reflected by the maria does not show at any season infrared reflection characteristic of the green chlorophyll of plants It is true that some primitive plants like lichens and liverworts do not exhibit chlorophyll spectrum in reflected light, so that the reflective properties of the Martian maria could perhaps be attributed to the existence of some sort of vegetation But such vegetation could only be of the most primitive kind Mars, therefore, as Sir Harold Spencer Jones has suggested, would seem to be at best a planet of spent and receding life of an extremely low order The choice thus lies between treating Mars as another arid, lifeless desert perched in the sky, or as something that will soon be one The new evidence yielded by the recent close-ups of Mars obtained by the USA's Mars flyby—Mariner IV—has not provided any ground to change this conclusion They are a remarkable series of photographs

taken at distances ranging from 4000 to 6000 miles only from Mars during a 25-minute sweep across the planet's southern hemisphere (Pl 8 and 9) They seem to suggest that Mars is a planet of broad desert stretches with an extremely rarefied atmosphere consisting of nitrogen, argon and carbon dioxide The existence of numerous shallow craters makes it resemble our moon more than the earth There is, therefore, little support for the idea that life can subsist on Mars But we may hope to learn more when instruments are landed gently into the crags of the moon and the maria of Mars We shall learn much about the origins of life and its mechanisms by seeing the products of evolution in other celestial climes We shall then know more positively than we do now whether life can be built on a radically different pattern with, say, silicon in place of carbon, chlorination in lieu of oxidation, controlled disintegration of radioactive atoms instead of photosynthesis and chemical combination, and a nervous system built on the principle of the wireless rather than that of the telephone exchange.

However, judging by present indications, our own earth seems to be the only abode of intelligent life in the solar system When we consider that barely 10 per cent of the stars in our Milky Way are born single and not every such star has a planetary system, and further that only 10 per cent of its planets may acquire the right blend of mass, axial rotation, distance, and other attributes likely to favour the emergence of life and intelligence, we may well appreciate how scarce and lonely life must be wherever in the universe it may have chanced to sprout. Assuming as a rough reckoning that not more than one star out of a million taken at random can possibly have a planet with life on it at some particular stage of development, there may well be hundreds of thousands of inhabited planets in our own Milky Way of some 200 billion stars In the larger universe of hundreds of millions of galaxies we may expect to find billions of inhabited worlds

CHAPTER FIVE

THE ARCHAEOZOIC ERA

(Lower Pre-Cambrian)

The earliest known history of the earth is recorded in rocks called Archaeozoic or Archaean which are variously estimated to be 2 500,000 000–1,375,000,000 years old The span of the Archaeozoic Era is believed to be over one billion years, which is about one-fourth of the age of the earth itself Fig 10 shows the ages and spans of successive geological eras of the earth and Fig 11 the ages and spans of geological periods since the Cambrian, with representative animal and plant forms

Comprising a crystalline complex and made up of various kinds of igneous and metamorphic strata the Archaeozoic rocks occur below the well recognized stratified deposits They form the core of all great mountain chains of the world, and the foundation of ancient plateaus

Archaean rocks in India The greater part of the Indian peninsula is occupied by the Archaean rock system (Fig 12) In Hyderabad, these rocks are eroded into fantastic forms like megaliths with boulders precariously perched on them (Pl 10)

Traces of Primitive Life

For a long span of time, our planet lay barren and lifeless The great continental platforms, rocky and bleak, were surrounded by vast oceans whose waters rose and fell in the form of tides

Being the oldest of the earth's crust, the Archaean rocks ought to show evidence of the earliest forms of life Owing chiefly to the extremely metamorphosed nature of these rocks and the delicate nature of the primitive life, hardly any determinable evidence of the earliest life has been obtained from the Archaean rocks The climate was favourable for the existence of life during this era Perhaps due to metamorphism, all the life that existed perished without leaving behind any trace Indirect evidence that life might have existed during the Archaeozoic is provided by the occurrence of beds of graphite, limestone and iron ore Graphite is of organic origin The enormous quantities of crystalline limestone together with bedded graphite schists may be of algal origin, since algae alone are capable of precipitating lime carbonate The occurrence of iron ore perhaps implies the existence of bacteria in the Archaeozoic, since bacteria and other microorganisms

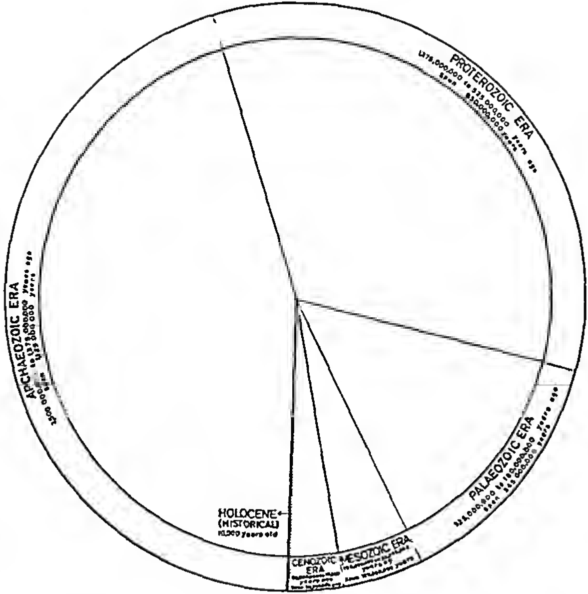


FIG. 10 THE AGES AND SPANS OF GEOLOGICAL ERAS

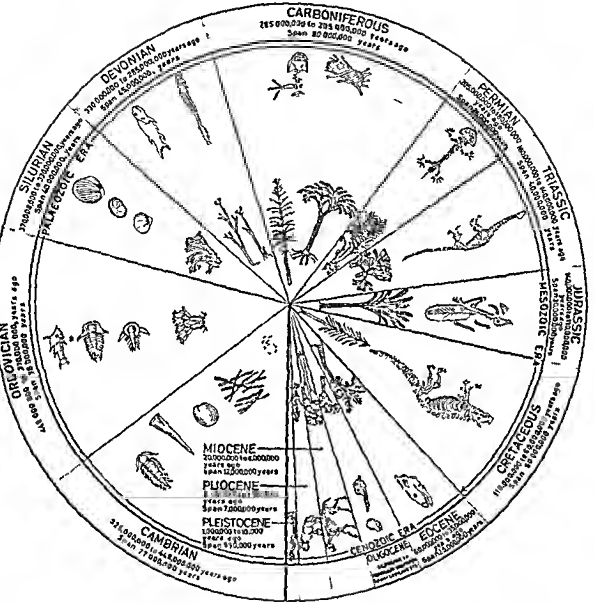


FIG 11 THE AGES AND SPANS OF GEOLOGICAL PERIODS SINCE THE CAMBRIAN, WITH REPRESENTATIVE ANIMAL AND PLANT FORMS

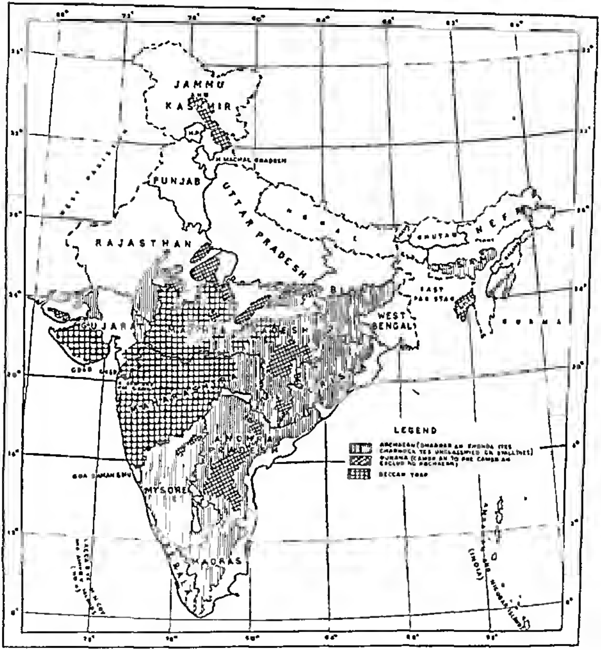
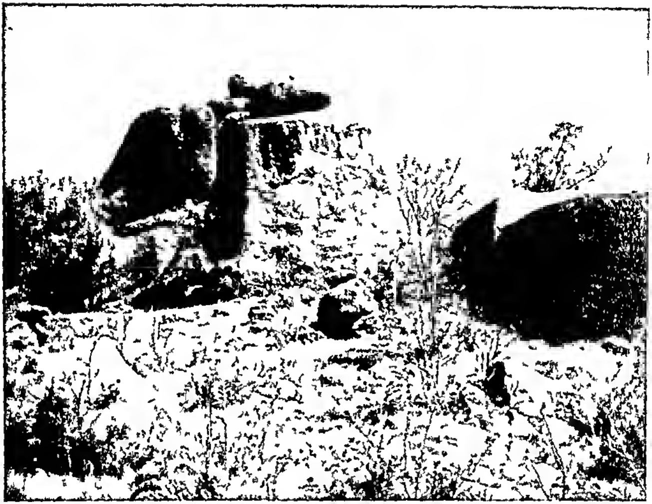
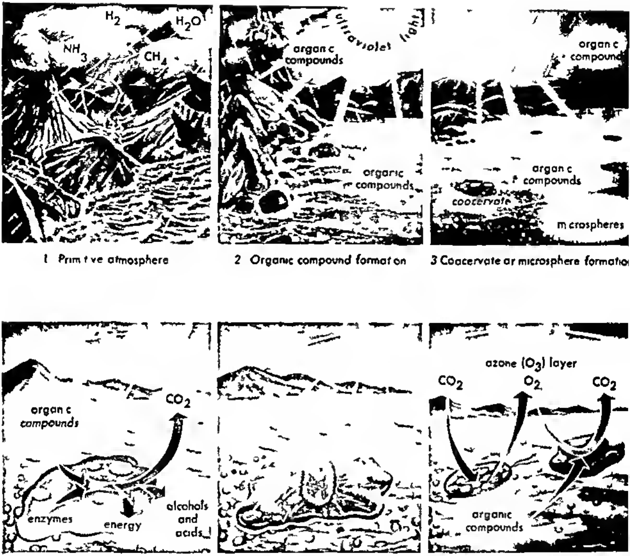


FIG. 12. MAP OF INDIA SHOWING THE OCCURRENCE OF ARCHAEAN AND PURANA ROCKS AND THE DECCAN TRAP



TYPICAL WEATHERING OF ARCHAEAN GRANITE ON BANJARA HILL HYDERABAD

This granite existed before life appeared on the earth



1 Primitive atmosphere
2 Organic compound formation
3 Coacervate or microsphere formation
4 Simple fermentations
5 Nucleic acid control
6 Photosynthesis and respiration

Biological Science: Molecules to Man. Houghton Mifflin Company, Boston

POSSIBLE PATHWAYS OF EARLY ORGANIC SYNTHESES LEADING TO THE PRIMITIVE CELL

are known to cause the deposition of ferric hydroxide It is on this basis that the iron formation in the Hudson's Bay district of North America has been attributed to bacterial action.

A few fossil forms have, however, been discovered from the Archaean rocks In Finland, small sac-like, sausage-shaped forms have been recovered from the late Archaeozoic rocks and these are believed to be the remains of primitive algae The hemispherical masses, the Eozoon, with crude concentric layers of lime carbonate and the *Atikokania*, the crude, cone-shaped masses with both concentric and radial structures, the latter known from the limestones in the Rainy Lake region of south-western Ontario, are believed to be plant secretions most probably of algal origin

The Archaeozoic Era is unfortunately devoid of any life forms From the direct or indirect evidence mentioned above one may surmise that life was very simple, comprising predominantly of viruses, bacteria and primitive algae Even to reach this level of organization, it required a time span of over one billion years.

ORIGIN OF LIFE*

Research during the last two decades has clearly established that the chemical Deoxyribose Nucleic Acid (DNA) constitutes the chemical substance of heredity in all living organisms, excepting some plant viruses in which the chemical involved is Ribose Nucleic Acid (RNA) DNA and RNA are the only chemicals with the property of self-replication, an essential requirement of life. For understanding the origin of life on earth, we have to unravel the mechanisms which led to the origin of DNA and to the subsequent evolution of DNA into genes and chromosomes which are the determinants of heredity. Prof J Lederberg has recently made the following convenient grouping of the stages involved in the origin and evolution of life

CHEMOGENY—During this stage, complex organic compounds were produced by a variety of non-replicative mechanisms such as the primitive cosmic aggregation, photochemistry of isolated atmospheres, and thermal and spontaneous reactions of inorganically catalysed, previously formed regions

BIOGENY—This stage marks the beginning of the replication of the specifically ordered polymer, DNA, which specifies the sequence of its own replicas, and of the working materials like RNA and proteins from which cells and organisms were fashioned. Random experiments of error in replication and natural selection of their developmental consequences, resulted in the panoply of terrestrial life.

*The portion on Origin of Life (pp 39 53) in this chapter has been contributed by Dr M. S Swaminathan Director IARI, New Delhi

COGNOGENY—This stage marks the evolution of the mechanisms of perception, computation and symbolic expression and interpersonal communication, whereby tradition can accumulate, culture unfold.

Chemogeny

Approximately 140 years ago, experimental investigations disclosed that the organic compounds which are found in living systems do not require those systems for their production In 1828, Wohler demonstrated that a chemist could synthesize an organic compound, urea, from inorganic reactants Since 1950, experiments have been performed and interpreted to indicate that the synthesis of organic compounds not only did not require a cell, it did not require a chemist either All that was necessary was the appropriate reactants and suitable geophysical conditions Thus, Calvin and coworkers were able to obtain formaldehyde and formic acid by exposing carbon dioxide and water to a simulated primordial geochemical environment Such work was followed by the experiments of Miller and Urey in which four proteinogenous amino acids were obtained by releasing electric discharges in a reducing atmosphere Thus, ample evidence became available to indicate the probable pathways through which amino acids and proteins can arise from simple inorganic compounds

The idea of the spontaneous generation of life from non-life was a very controversial one for many years Louis Pasteur, who showed by simple experiments that life can arise only from pre-existing life, had, however, envisaged that life in its initial form could have arisen from non-living matter In 1878 he wrote "Spontaneous generation—I have been looking for it for 20 years but I have not yet found it, although I do not think this is an impossibility" Pasteur's experiments, which demonstrated convincingly that bacteria and other microorganisms can only arise from pre-existing bacteria or other organisms and that the *de novo* origin of life in any decaying organic medium is impossible, led to the wide acceptance of the view that the spontaneous generation of life is impossible Today, we can again speak of the spontaneous generation of life but not in the sense Pasteur meant it, b[illegible]om the view point of the spontaneous generation of organic compounds over mill[illegible]f years and the subsequent origin of the first primitive living system

One of the major energy sources for early chemical reactions on the primitive earth was probably ultraviolet light, although other energy sources could have existed The ultraviolet light which now reaches the surface of the earth is only a small fraction of what probably reached it two billion years ago This is due to the presence of a layer of ozone in the upper atmosphere which filters out most of the ultraviolet component of the sun's light The very products of early evolution required, and had, an environment conducive to the synthesis of complex organic molecules, ultimately giving rise to living units capable of metabolic activity These primitive cells gradually changed the environment by the metabolic evolution of O_2 and the subsequent formation of an UV shielding ozone layer to such a point where the primitive synthetic processes could not proceed on the same lines Thus, further biological evolution was essential for the development of life Pl 11 gives a diagrammatic sequence of possible pathways of early organic syntheses leading to the primitive cell

Biogeny

Most of the present day thinking on the origin of life is derived from an essay J B S Haldane wrote on this subject in 1925 This changed the thinking of biologists from hypotheses based on rather complicated organisms arising out of a simple environment to very simple forms of life arising in a complex chemical environment To quote Haldane's words, 'When ultraviolet light acts on a mixture of water, carbon dioxide and ammonia, a vast variety of organic substances are made, including sugars, and apparently some of the materials from which proteins are built up Before the origin of life they must have accumulated until the primitive oceans reached the consistency of hot, dilute soup' The Russian biochemist, A I Oparin, expressed similar views and stated, "At first there were the simple solutions of organic substances whose behaviour was governed by the properties of their component atoms and the arrangement of these atoms in the molecular structure But gradually, as a result of growth and increased complexity of the molecules new properties have come into being and a new colloidal chemical order was imposed upon the more simple organic chemical relations" Such a process leads to the formation of microspheres or coacervates which are sometimes regarded as the first step in the origin of life With the demonstration during the last two decades that Deoxyribose Nucleic Acid (DNA) constitutes the primary chemical substance of heredity in all living organisms excepting in some plant viruses (where ribose nucleic acid or RNA is the chemical involved), a new chapter in pre-biological chemistry was opened up Attempts have been in progress in several laboratories to get polynucleotides synthesized from chemicals which are presumed to have existed in the 'hot dilute soup" of Haldane

By reproduction, life thwarts time The main molecular phenomenon underlying reproduction is the replication of the genetic material, i e DNA Occasionally, the DNA molecule commits slight errors in the process of duplicating itself These small changes, which are manifested in the form of mutations, are the raw material of evolution According to Darwin's theory, evolution progresses due to the action of natural selection on the variations which were shown by De Vries to be generated by mutations

However, the ability to replicate itself is not the only property of the DNA molecule It can also direct the synthesis of protein molecules, which are the basis of cell structure and function The synthesis of proteins is a constellation of biochemical events in which the genetic message encoded in the sequence of the 4 different building blocks of DNA, i e adenine, guanine, cytosine and thymine, is transcribed and translated into the sequential linking up of 20 different kinds of amino acids by heptide bonds The central problem pertaining to the origin of life is the evolution of the highly specific DNA molecules How did the DNA molecule evolve from inorganic precursors ? How did it acquire the ability to replicate and to encode the genetic message ?

The first insight into the abiological synthesis of nucleic acids was obtained from the experiments of S W Fox, who showed that thermal polymerization of amino acids under conditions simulating that of the primitive atmosphere produces along with a variety of other compounds, ureidosuccinic acid The latter compound is known to be a key intermediate in the biosynthesis of nucleic acid bases Chemical analysis of proteinoids obtained in the above experiment also demonstrated that the nucleic acid base guanine can be synthesized in this way

J Oro, working in the Department of Chemistry at the University of Hanston Texas, showed that prolonged heating of a concentrated solution of hydrocyanic acid in aqueous ammonia at a temperature of 100°C produced adenine Adenine is not only one of the four nitrogenous bases of DNA but also a most important coenzyme For example, it is the building block of adenosine triphosphate, the biological energy currency

The reasons for employing hydrocyanic acid as the starting material in the above experiment are as follows

(*a*) Hydrocyanic acid is considered to be an intermediate in the synthesis of amino acids from primitive gas mixtures

(*b*) Urey has postulated that since the origin of the earth more than 4 billion years ago, several comets have collided against it, strewing the surface with carbon compounds Since hydrogen cyanide occurs in the tails of comets, it is reasonable to postulate that the primordial atmosphere of primitive earth contained large quantities of hydrogen cyanide or its reaction products

More recently, starting with purine precursors, Oro was able to achieve the non-enzymatic synthesis of guanine and uracil.

Ponnamperuma and his associates of Exobiology Laboratory of NASA obtained adenine by irradiating a mixture of methane, ammonia, hydrogen and water with a high energy electron beam which simulated the energy emitted from potassium-40 spread over the primitive earth. Subsequently, the same group of workers irradiated an aqueous solution of hydrogen cyanide with ultraviolet light. The radioautogram of the paper chromatogram of the reaction product revealed the formation of adenine, guanine and urea.

Apart from the purine and pyrimidine bases, DNA and RNA consist of phosphate groups and the pentose sugars, deoxyribose and D-ribose.

The simplest sugar that is formed abiologically is formaldehyde. It has been shown that absorption of UV by formaldehyde gives rise to a series of sugars which includes deoxyribose and D-ribose.

How did the purine and pyrimidine bases link up with sugar and phosphate to give rise to the building blocks of DNA and RNA? How did these building blocks polymerize to give rise to the nucleic acids?

$$\underbrace{\underbrace{\underbrace{\text{Adenine}}_{\text{Base}}\text{—}\underbrace{\text{Deoxyribose}}_{\text{Sugar}}}_{\text{Nucleoside}}\text{—Phosphate}}_{\text{Nucleotide}}$$

Ponnamperuma and Young have suggested that activation of purine and pyrimidine bases by UV facilitated their linking up with sugar molecules to give rise to nucleosides or deoxynucleosides. They have also shown that irradiation of adenine and ribose by UV in the presence of a phosphate gives rise to adenosine. They have further shown that UV irradiation of adenine, ribose and the ethyl ester of polyphosphate produces adenosine diphosphate and adenosine triphosphate. Thus, ATP (adenosine triphosphate), the biological energy currency, could also be produced abiologically. Schramm has emphasized the possibility of polyphosphate esters playing an important role in the evolution of nucleotides and their subsequent polymerization to polynucleotides. This possibility gains support from the observation that even in the organisms living today polyphosphate esters like ATP continue to play a similar role. Further, some primitive microorganisms accumulate large quantities of polyphosphates which can be incorporated into organic compounds as needed.

Schramm's suggestion is *in accord* with known biochemical facts Phosphoric acid occurs only in the form of polyphosphates above a temperature of 300°C It is quite conceivable that as the earth crust began to cool, a large supply of polyphosphates and reactive phosphorus oxides were available which reacted with purines pyrimidines and sugars to give rise to polynucleotides

The primitive polynucleotides which were thus synthesized most probably had a random arrangement of the monomers, i e a random base sequence and consequently they were incapable of specific function. It is highly unlikely that a chance arrangement of monomers would have given rise to even the most primitive imaginable organism So rare an event could *not have* occurred in the finite time span during which the earth has existed There is indeed a large gap between randomly formed nucleic acids and proteins and the origin of life

However, one can conceive of the primitive polynucleotide with a randomly arranged base sequence, and incapable of specific function, evolving in slow steps to form a polynucleotide with non-random base sequence and capable of specific functions

Experiments of Mirsky indicate that the primitive polynucleotide probably was incapable of specific information, storage and transfer but probably was capable of a non-specific but important function, i e catalysing the synthesis of polyphosphate esters, e g ATP The following paragraph briefly describes these interesting experiments

Mirsky showed that small polynucleotides or larger ones of simple composition can perform the important function that is normally performed in the cell by complex and specific nucleic acids consisting of thousands of nucleotides It is experimentally possible to substitute the DNA of the nucleus by these non-specific nucleotides if the structural background of the cell is not tampered with. Nuclei isolated from calf thymus are known to synthesize protein under certain conditions as revealed by the uptake of radioactive amino acids When the DNA of calf thymus nuclei is digested out by DNAase (deoxyribonuclease), an enzyme which specifically attacks DNA, the nuclei lose their ability to synthesize protein It is possible to restore the protein synthesis by adding extraneously di- or trinucleotides or larger nucleotides of very simple composition, e g poly A—a polynucleotide containing only adenosine monomers ATP synthesis is closely linked with protein synthesis. DNAase digested nuclei lose their ability to synthesize ATP and consequently the ability to synthesize proteins Restoration of DNA even in the form of di- or trinucleotides also restores ATP and thereby protein synthesis

The fact that small non-specific nucleotides can catalyse ATP synthesis indicates that this might have been the original function of primitive polynucleotides which lacked the specificity to function in the transmission of heredity During the course of evolution

these polynucleotides have acquired the complexity and the specificity needed to encode the message of heredity

Another question which is to be answered in this context is *What are the minimum conditions for the evolution of a self-replicating system?*

For a possible answer one can again look at the relevant molecular events taking place in organisms living today. On the basis of steric and chemical evidences, Watson and Crick showed that the 2 polynucleotide helices of DNA have a base composition complementary to each other and that complementarity of base composition is the primary requirement for 2 polynucleotide strands to pair (Pl 12) Meselson and Stahl have demonstrated that a strand of polynucleotide serves as a template or a matrix for the synthesis of a complementary strand, which *in turn* serves as the template for the synthesis of the original strand Symbolically, *matrix* M catalyses the formation of the complementary matrix M_C which in turn catalyses the synthesis of the original matrix M

$$\begin{array}{ccc} M & \rightleftarrows & M_C \\ \uparrow & & \swarrow \\ & \text{Protein} & \end{array}$$

Also, M and M_C mediate the synthesis of a protein which in turn controls the replication of these matrices

Schramm has shown that these mutually and catalytically interacting matrices of polynucleotides and proteins (enzymes) are paralleled even under the conditions of

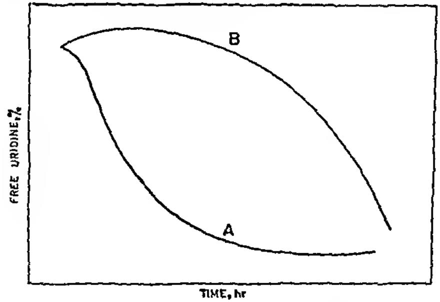


FIG 13 POLYMERIZATION OF URIDINE MONOPHOSPHATE IN THE (A PRESENCE AND B) ABSENCE OF POLYADENYLIC ACID

non-enzymatic synthesis of polynucleotides He has shown that the non-enzymatic or abiological synthesis of polyuridylic acid is accelerated 10-fold in the presence of polyadenylic acid (Fig 13)

This clearly indicates that polymerization of a polynucleotide strand is favoured by a complementary strand One can then argue that, if in the course of chemical evolution the formation of nucleotide strand carried any selective advantages, then these in turn favoured the synthesis of complementary strand, which in turn speeded up the synthesis of the original strand It is imaginable how such a system may gradually gain perfection

Schramm also showed that polyarginine, a synthetically prepared polypeptide, speeded up the formation of a polynucleotide chain It remains to be seen whether polynucleotides do favour the abiological synthesis of polypeptides

Thus, it has been possible to re-enact in the laboratory the first few scenes of the great drama of the origin of life and to gain insight into the guiding principles which have determined the sequence of events in this great event

Evolution of Chromosome Organization

For a variety of reasons, the genetic material in all higher organisms is organized into chromosomes Chromosomes are rod-like bodies found in a dividing nucleus (Pl 13)

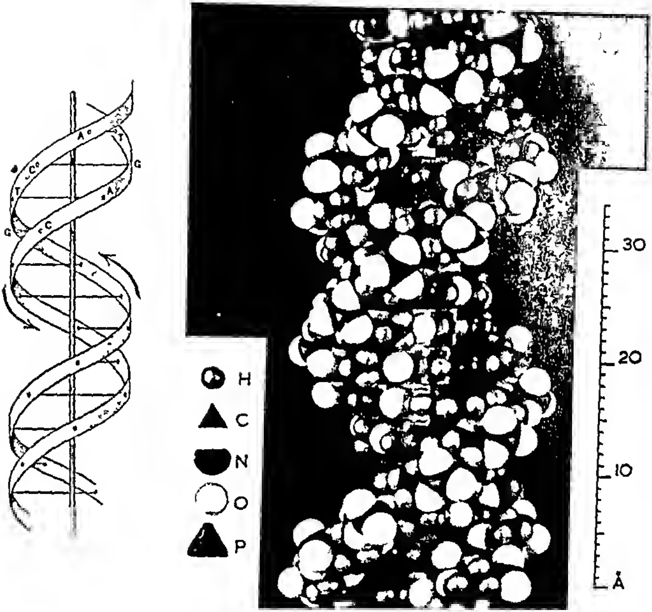
Chemical analysis has revealed that DNA and histones are the major chromosomal constituents The absolute amount of DNA and histones per chromosome remains constant throughout the cell cycle In addition to these, chromosomes also contain a variable amount of minor constituents such as RNA and acidic proteins (Pl 14)

Optical and electron microscopic analysis of chromosomes has revealed their multistranded nature Electron microscopy has further aided cytologists in identifying the basic building block of chromosomes—a microfibril, 200–250 Å in diameter These fibrils consist of DNA and histones The presence of histone enables the lateral linking up of several DNA strands of similar base composition to give rise to a multistranded chromosome (Pl 14 and 15, Fig 14) The precise 3-dimensional pattern in which these microfibrils are woven into the chromosomal fabric, however, is not clear

What are the different stages in the evolution of the complex chromosomes of higher organisms from the primordial, abiologically synthesized DNA molecule?

Electron microscopic studies of chromosome organization of organisms living today has provided a partial answer to this question

The most primitive and the simplest kind of organization of the genetic material is found in the prokaryotes, i e a group of organisms lacking in (i) organized chromosomes, (ii) nuclear membrane, and (iii) mitosis Bacteria, bacteriophages, viruses, and blue-green algae are organisms belonging to this class Electron microscopy of the nuclear material



THE MOLECULAR MODEL OF DNA POSTULATED BY WATSON & CRICK

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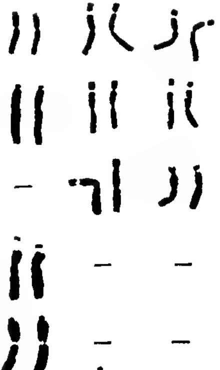

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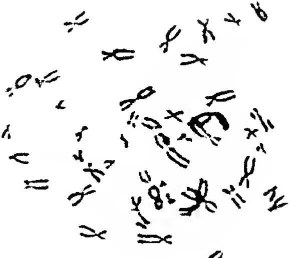

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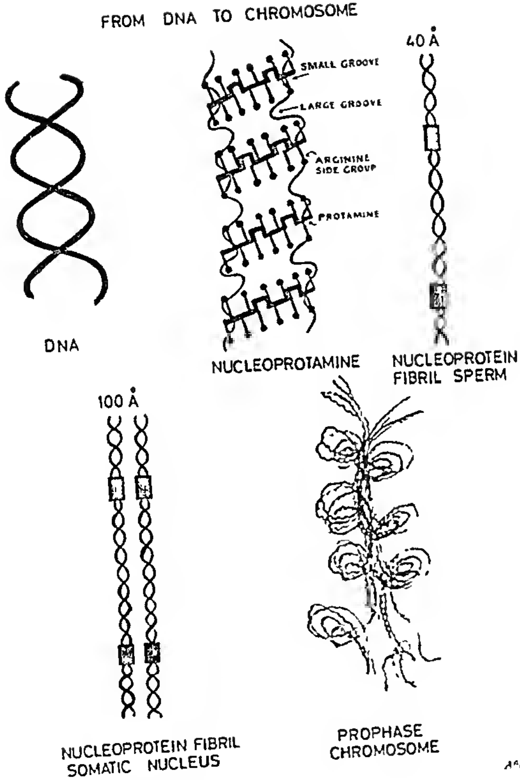
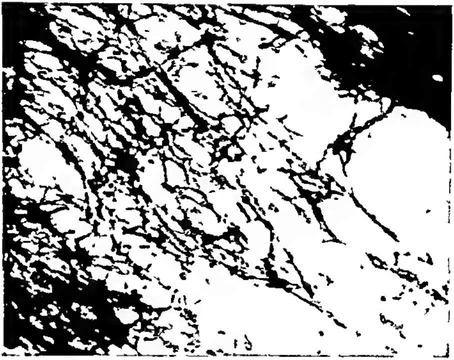
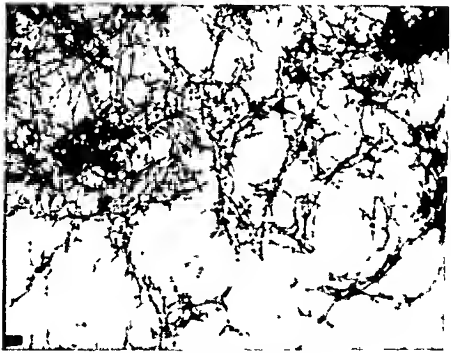


THE PATTERN OF ORGANIZATION OF DNA INTO CHROMOSOMES





ELECTRON MICROGRAPHS OF CHROMOSOMES OF FROG SHOWING HELICALLY COILED 200–250 Å MICROFIBRILS (×45,520)

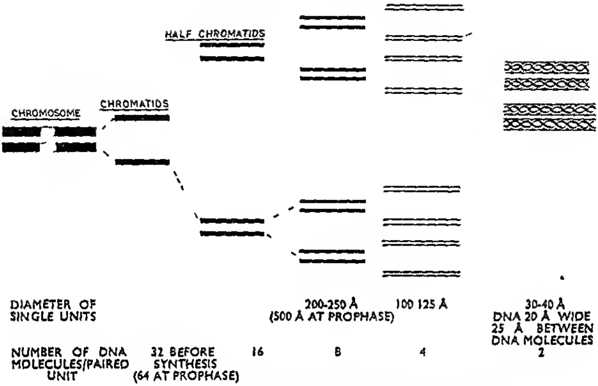


FIG 14 THE MULTISTRANDED NATURE OF CHROMOSOMES (After Steffenson)

of prokaryotes reveals 25 Å DNA fibrils which do not have any regular geometrical arrangement Cytochemical techniques indicate the absence of histones The DNA of bacteria (Fig 15 1) and T-even phages appears to exist in the form of a circle—a fact which is in accord with the occurrence of circular linkage maps in these organisms

The next in the order of increasing sophistication of chromosome organization are dinoflagellates—a group of unicellular organisms The dinoflagellate chromosomes (Fig 15 2), unlike those of higher organisms are visible throughout the division cycle of the cell Histones are again absent and the process of mitosis is of a primitive type The DNA fibrils in dinoflagellate chromosomes show a regular 3-dimensional arrangement unlike those of prokaryotes Hans Ris is of the opinion that the chromosomes of dinoflagellates represent an intermediate order of organization between those of prokaryotes and higher organisms (Eukaryotes)

The next in the sequence of chromosome evolution was the origin of the type of chromosome we see in all higher organisms Here the chromosome has a well defined morphology The chromosome number is usually constant for a species and varies between species or genera The lowest chromosome number in animals occurs in the roundworm *Ascaris* which has 2 chromosomes in the body cells, and among plants, in

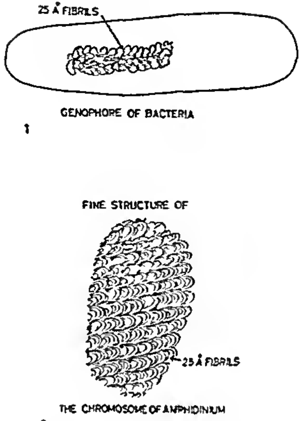


FIG 15 THE ORGANIZATION OF NUCLEAR MATERIAL IN 1 bacteria 2. *Amphidinium* a dinoflagellate

Haplopappus gracilis which has 4 chromosomes in the somatic cells Some ferns like *Ophioglossum* have over 1200 chromosomes

The chromosome type of organization of genetic material provides a means of maintaining a balance between stability and variability, a feature essential for the survival of species Because different genes may be located on different chromosomes, the law of independent assortment of genetic factors postulated by Gregor Mendel can operate efficiently This phenomenon enables the origin of extensive new variability through the continuous reshuffling of genes Thus, starting with the simple type of organization found in bacteria and blue-green algae, we find that in nearly all higher organisms, well organized chromosomes serve as the carriers of hereditary particles

Evolution of Genetic Regulatory Mechanisms

Since in multicellular organisms, all the cells arise from a single initial cell (zygote) it is clear that all cells contain identical chromosome sets and genetic factors Under

such conditions, the cell should have the potency to express all the characters of the organism. Fig. 16 shows, diagrammatically, different steps in the operation of the genetic code. That this is indeed the case has been demonstrated by F.C. Steward and his colleagues in the United States who produced in artificial cultures entire carrot plants from individual cells of the carrot roots. Similarly, E. Hadorn of Zurich has shown that cells of the imaginal disc of the fruit fly *Drosophila melanogaster* form wings, antennae, legs or genital organs in culture tubes. While the cell is thus totipotent, the differentiation of cells into tissues and organs demands that not all genes can be active in all cells. There has to exist a system of selective activation (derepression) and inactivation (repression) of genes in different cells. Probably only a small portion of genes are active at any one time. The processes which regulate genes are currently one of the most fascinating areas of research.

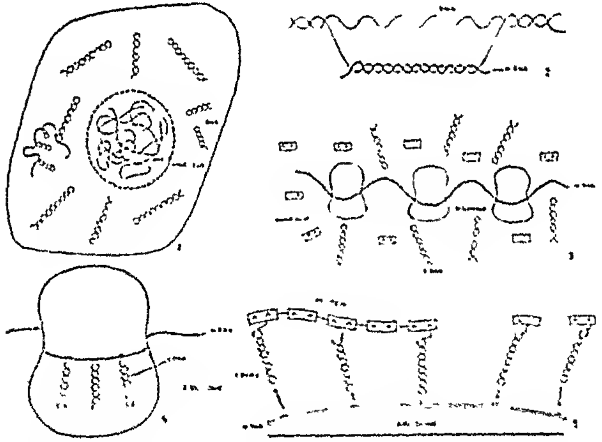


Fig. 16. Different steps in the operation of the genetic code. 1, Cell showing the presence of DNA in the nucleus. 2, Synthesis of Messenger RNA by derepressed DNA. 3, Ribosomes with Messenger RNA and Transfer RNA. 4, Arrangement in the ribosome of m-RNA and t-RNA. 5, Formation of the polypeptide chain at the ribosome

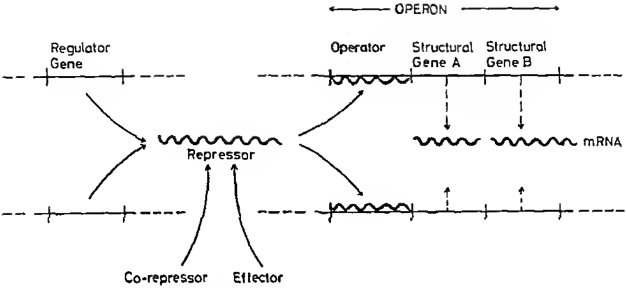
There appear to be at least two levels of gene control. One of these involves a very selective control of individual structural genes. The other involves the inactivation of whole chromosomes. The genetic systems that control gene action are best understood in bacteria and the system proposed by the French scientists Jacob and Monod serves as the basis for studies in this field (Pl. 16). The bacterial control systems are composed of two genetic elements, each distinct from the structural gene. One of them designated the 'operator', is located adjacent to the structural gene (or sequence of structural genes) and controls its activation. The structural gene, when activated, is responsible for the production of a particular sequence of amino acids and thus for the specificity of a protein. The second element of this system, termed the 'regulator', may be located close to the structural gene or it may be located elsewhere in the bacterial chromosome. The regulator is responsible for the production of a repressor substance that appears in the cytoplasm. The operator element responds to changes in degree of effective action of the repressor substance by 'turning on' or 'turning off' the action of the structural gene in accordance with such changes. Each operator-regulator system is specific in that an operator will respond only to the specific product of the regulator of its system. Cytoplasmic feed back is thought to occur through influences on stability of the repressor-operator complex.

Knowledge of regulator genes is still largely restricted to microorganisms. Operon systems of control are, however, suspected in several higher organisms including man. At the level of the chromosome, uncoiling and dissociation of the DNA from the histone are believed to play an important part in gene activation. Gene action is usually repressed in a tightly coiled chromosome segment The potentiation of the nucleotide sequence within a gene for the formation of an RNA copy requires that the histone component be separated from the nucleic acid. Frenster has recently postulated that the polyanions present in the chromosomes such as RNA, phosphoproteins, phospholipids and non-histone residual proteins may displace histones from DNA and thus help in genetic derepression (Pl 17). Mechanisms of this kind help in differential gene action.

To summarize, the polynucleotides synthesized at the dawn of life soon got organized into an orderly sequence. This orderliness reached a high state of elegance in the chromosomes of higher organisms Systems of regulation of gene action soon arose, which set in motion a chain of differentiation mechanisms and thereby led to the origin of multicellular organisms, with well differentiated organs, from simple unicellular organisms.

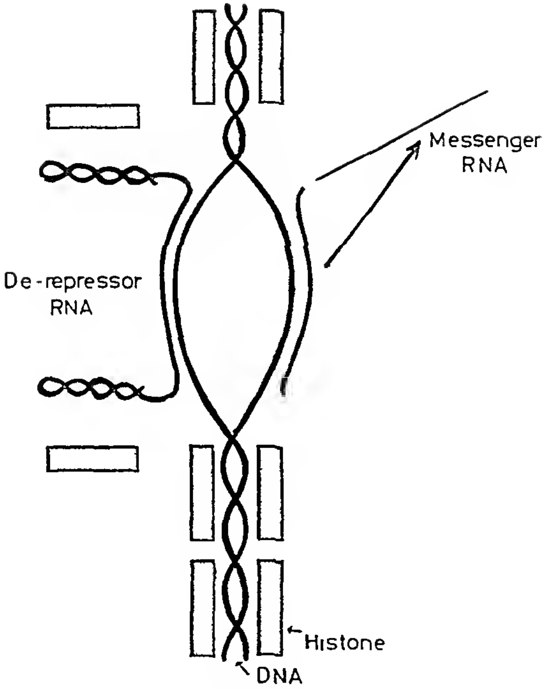
Time Factor in Evolution

Blake wrote in 1793 that "to create a little flower is the labour of ages", a beautiful way of expressing that evolution is a very slow process. Haldane guessed that if two species of mammals differed from each other by a thousand genes, it would take about



GENE RELATIONSHIPS IN A DIPLOID ORGANISM
(Based on Lac locus in E coli)

THE OPERON MODEL OF REGULATION OF GENE FUNCTION POSTULATED BY JACOB & MONOD



THE MECHANISM OF DEREPRESSION OF REPRESSED DNA POSTULATED BY FRENSTER

half a million years for the origin of a new species Recently, fairly precise estimates of the rate of evolution of genes determining the structure of the blood-cell protein, cytochrome C, have become available A rough estimate for mammals is one gene replacement every 10 million years Regarding this as 3 million generations, this is about 1/10,000 of the number of substitutes expected with Haldane's theory This is consistent with there being about 10,000 times as many genes altogether as there are those determining haemoglobin structure Thus, Haldane's calculation seems to be substantially correct and provides an idea of the time factor involved in the later stages of evolution

Evolution of Enzyme Systems

The metabolic reactions of living organism are mediated by biological catalysts called enzymes It is interesting and highly suggestive that most of the enzymatic reactions taking part in a living organism can be mimicked by the chemist in the laboratory using non-enzymatic catalysts For example, freshly precipitated trivalent metal hydroxides can catalyse the same reactions which are mediated by phosphatases in the living organisms

One particular group of catalysts which is centred round the element iron, e g catalase, peroxidase and cytochrome, is very instructive, because in this case a comparison can be made in quantitative terms between the catalytic ability of the bare iron atom and the iron containing enzymes of living organisms The incorporation of an iron atom into a porphyrin, i e haem, and the incorporation of iron porphyrin into a protein as in the case of catalase, boosts the catalytic efficiency from 10^{-5} to 10^{5}

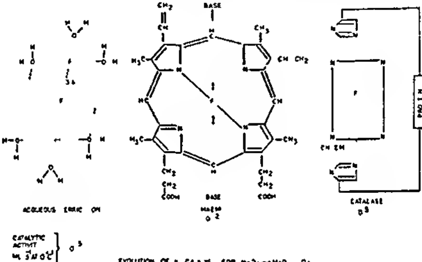
Melvin Calvin has pointed out that in order to convert the rudimentary catalytic ability of elements and their simple compounds into the highly efficient catalysts in the form of enzymes, two concepts, one from chemistry and the other from genetics, have to be invoked.

The concept from chemistry is autocatalysis, i e the ability of the product of a reaction to catalyse the conversion of the precursor into itself For example, cupric ions get converted into cuprous ions in the presence of molecular hydrogen In the absence of a catalyst, the reaction would be inordinately slow However, it so happens that cuprous ion itself catalyses this reaction, accelerating it manifold

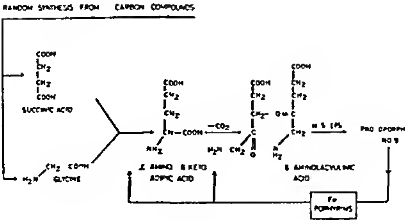
The other concept which is relevant in this context has come from the geneticist Horowitz, who has suggested that the very complex and interacting series of reactions which are responsible for the synthesis of most of the biological material in present day organisms could have evolved in a backward manner from completely heterotrophic organisms He has postulated that the first living things were complete heterotrophs and all the precursors for their own duplication were available to them. It is conceivable that when one essential precursor gets depleted, only those units would survive which

have found a way of synthesizing the depleted precursor Such a process of progressive depletion of essential precursors with the evolution of more complex chains of reactions to synthesize them, has resulted in the complex metabolic pathways one finds in organisms living today

With these concepts it is possible to conceive of a process leading to the formation of an efficient catalyst One can consider a particular example such as the synthesis of iron porphyrin It is known that glycine and succinic acid which can be produced abiologically from primitive gas mixtures are the precursors in porphyrin synthesis Assuming



EVOLUTION OF A CATALYST FOR $H_2O_2 \rightarrow H_2O + O_2$
(After Calvin)



CATALYTIC FUNCTION OF IRON
(After Calvin)

that one or more steps in this reaction are dependent on iron catalysed oxidation, it is easy to see how iron with its catalytic ability boosted up manifold due to its incorporation into the porphyrin group, would autocatalyse its synthesis Thus, complex enzymes could have evolved from crude elemental catalysts like iron by a process of autocatalysis and the progressive improvement of the catalytic ability of the elemental catalyst by its association with some of the intermediaries in the reaction

SIMPLE FORMS OF LIFE

Filterable viruses The simplest organisms known are filterable viruses which are so small that they can pass through filters, and are hence also called 'Filter-passers' They are smaller than bacteria, and cause certain diseases such as measels, infantile paralysis, rabies, cattle-pneumonia and foot and mouth disease In plants they cause many diseases Yellow leaves and leaf mosaic seen in many plants are due to viruses They cannot be seen under the ordinary microscope, and can only be photographed under an electron microscope On account of their transparency they are difficult to photograph and their outlines are revealed when plated with molecules of gold. Thus, their identity has been established only on photographic plates, and they cannot actually be seen by the human eye The filterable virus associated with cattle-pneumonia is like a tiny ball, which swells up, little protuberances arise on its surface, which get nipped off, and these in their turn reproduce in a similar manner Thus, it possesses the main attribute of living matter, the capacity to reproduce itself According to some, the ancestors of viruses were free living pre-cellular forms of life which managed to survive by becoming parasitic on cellular organisms According to another view, they have arisen from detached fragments of the genetic material of cellular organisms

Bacteriophages Like the filter-passers, the parasites of bacteria, called 'bacteriophages' are on the borderland between the inert and living matter De-Herelle, who discovered them, is of the view that they are alive, and they are able to reproduce themselves and multiply They continue to grow and multiply as long as they get supplies to consume The bacteriophages and filterable viruses can be regarded as providing a link between the two states of matter—the living and the non-living

Bacteria. They are tiny organisms, usually about 125 000th of an inch in diameter Bacterial cells exhibit three fundamental shapes they are rod-shaped (bacilli), round (cocci), or wriggling (spirilli) (Fig 17) The wrigglers have hair-like appendages which propel them No obvious internal structure can be discerned Two species which appear identical may have different effects, one may cause a deadly disease, and the other may be useful to human beings Pathogenic bacteria cause diseases such as tetanus, diphtheria,

tuberculosis, gastroenteritis, typhoid, cholera, syphilis, etc. There are many bacteria which are our friends. They fix nitrogen in the soil, and are useful in the preparation of sour milk, vinegar and cheese. They flavour wines, cure tobacco, tan leather and assist in the retting of jute. Bacteria are extraordinarily resistant to heat and cold, and are known to have survived, even after six months in liquid air at $-190°C$. They breed by fission at a rapid rate, about once every half an hour. It has been estimated that if the

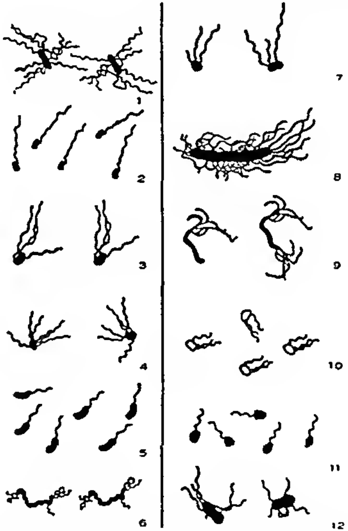


FIG. 17. BACTERIA. 1-6, PATHOGENIC BACTERIA: 1, *Clostridium tetani* (cause of tetanus); 2, *Corynebacterium diphtheriae* (cause of diphtheria); 3, *Salmonella typhimurium* (cause of gastroenteritis). 4, *Salmonella typhosa* (cause of typhoid). 5, *Vibrio cholerae* (cause of cholera). 6, *Treponema pallidum* (cause of syphilis). 7-12, NON-PATHOGENIC BACTERIA 7, *Lactobacillus* sp (used in dairy). 8, *Bacillus megaterium* (phosphorus solubilizing bacterium); 9, *Rhodospirillum rubrum* (photosynthetic nitrogen fixing bacterium). 10, *Acetobacter aceti* (used in vinegar production). 11, *Methanomonas methanica* (indicator of petroleum source). 12, *Azotobacter chroococcum* (nitrogen fixing bacterium found in the soil) (*After Leifson, 1960*)

entire progeny of a single bacterium is kept alive, it would total 281,476,587,353,856 members by the end of one day

A kind of bacterium eats bricks, is also found on decaying stones, and doubtless it is a type of organism which helped to manufacture soil from barren rocks and mountain peaks in the earth's youth, thus making the world fit for higher plants and animals to live in

Very probably bacteria had become fairly abundant in the Archaeozoic Era Recent electron microscopic study of Gunflint chert, a sediment in southern Ontario, Canada, by Schopf, Barghoorn, Maser and Gordon of Harvard University has revealed the occurrence of well preserved rod-shaped and coccoid bacteria The age of the chert is estimated at 1900 million years, viz. the early Archaeozoic Era This appears to be the oldest definite occurrence of bacteria in the fossil record The rod-shaped bacteria are about 1 1μ long and 0 55μ wide They are found as isolated cells, in clumps of 6–8, or in chains up to 7 cells long False branching has been observed in some cases The coccoid bacteria-like objects are 0 35μ in diameter These organisms are morphologically comparable with certain forms of present day iron bacteria It is thus possible that anaerobic heterotrophic bacteria were among the earliest forms of living organisms on this planet

Blue-green algae. Following the appearance of differentiated protoplasm, organisms resembling the present day blue-green algae may have been among the first to evolve Modern blue-green algae attain their greatest development under warm, humid, subaerial conditions, or in fresh waters They show great resistance to extreme conditions and exist in snow as well as in hot water springs Though they can tolerate high salt concentrations, they are not usually abundant in marine habitats This suggests that the major evolution of blue-green algae occurred when sea water was much less saltish than it is now There is some evidence that anaerobic conditions persisted almost to the Cambrian and the fact that most blue-green algae tolerate reducing conditions, and some species at least can utilize reduced inorganic compounds, suggests that these plants appeared before the atmosphere became oxidizing The pigmentation of blue-green algae might have originated as an adaptation to the low intensity of light on the surface of the primitive earth which was wrapped in dense clouds

The blue-green algae have some resemblances with bacteria, e g cell structure, type of reproduction, absence of chromatophores and a nucleus There are several bacteria which have the forms of *Aphanocapsa*, *Aphanothece*, *Spirulina* and *Oscillatoria* *Leuconostoc* offers a good comparison with some of the Chroococcales The filamentous bacterium, *Cladothrix* resembles *Tolypothrix* There is likewise, a similarity between *Crenothrix* and *Lyngbya* However, the blue-green algae differ markedly from bacteria in the absence of cilia and possession of pigments and are thus more advanced organisms

The blue-green algae seem to have passed through different evolutionary stages in geological time. The simplest types now in existence, resembling most closely the ancestral forms are unicellular forms like *Chroococcus*, *Synechococcus*, *Microcystis*, *Aphanocapsa* and *Gloeocapsa* belonging to Chroococcales. The only type of reproduction known in them is by fission or simple cell division in one, two or three planes. In forms like *Aphanocapsa* and *Gloeocapsa*, cell division takes place in three planes resulting in more or less spherical colonies, while in forms like *Merismopedia* and others, cell division takes place alternately in two directions, in one plane. In *Synechocystis* the cell division takes place in one direction only and there seems to be a tendency for the plant to stretch and elongate. From these simple one-celled organisms arose members of Chamaesiphonales and Pleurocapsales. They developed a distinct base and apex.

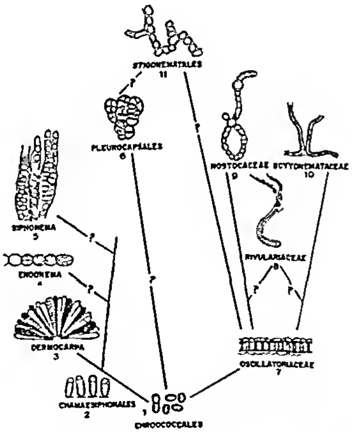


FIG. 18. SOME BLUE-GREEN ALGAE ARRANGED IN EVOLUTIONARY SEQUENCE. 1 *Chroococcus turgidus* 2, *Chamaesiphon incrustans* 3 *Dermocarpa xenococcoides* 4 *Endonema moniliforme* 5 *Siphonema polonicum* 6 *Pleurocapsa minuta* 7 *Oscillatoria sp* 8 *Calothrix parietina* 9 *Nostoc punctiforme* 10 *Scytonema crispum* 11 *Mastigocladus laminosus* (1 after Goyal 2, 5 & 6, after Geitler 3 after Setchell & Gardner 4 after Pascher 7 & 11 after Venkataraman 8 & 10 after Fremy 9 after Tilden)

The other line of advancement is the development of multicellular plants which form trichomes or rows of cells with or without an enveloping sheath as is seen in *Oscillatoria* and *Lyngbya* belonging to Oscillatoriaceae The sole method of reproduction in the members of these genera is by the formation of hormogones which are nothing more than a group of two or more cells that breaks away from the parent plant and develops into a new one (Fig 18)

Life During the Archaeozoic Era

The organization of living matter, probably, took place in the early part of the Archaeozoic Era It is very likely that before the Archaeozoic Era closed, primitive algae protozoa, coelenterates and possibly also sponges were in existence It is believed that the primeval oceans did not contain lime, and it was only when the rivers carried sufficient quantity of it into sea water, that some of the protozoa-like Foraminifera and Radiolaria acquired the habit of manufacturing shells which could be preserved as fossils

CHAPTER SIX

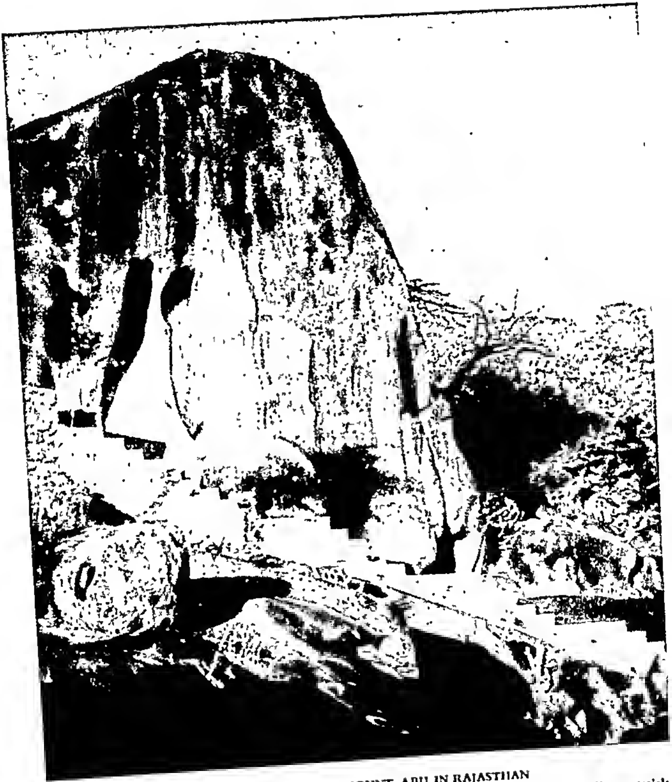
THE PROTEROZOIC ERA
(Upper Pre-Cambrian)
The Age of the Primitive Algae and Protozoa

The Proterozoic Era includes the time between the Archaeozoic and the Palaeozoic and is estimated to have lasted for 850,000,000 years The Proterozoic presented a barren landscape, with jagged rocks, and there was considerable volcanic activity It was also a period of active erosion, as the night and day temperatures were sharply contrasted, and there was no plant cover to bind the soil Torrential rains were followed by floods, which spread the disintegrated rocks and sand over the face of the earth. Avalanches of rocks and restlessly drifting sand dunes produced a weird landscape. Except for howling winds, it was a dumb world, for there were no animals on the land The Proterozoic closed with continental uplift and mountain building on a large scale, followed by intense glaciation North America was extensively glaciated and glacial deposits have also been located in Yangtse region of China, South Australia, South Africa, India and in the Salt Range of West Pakistan.

In India, rocks of the Proterozoic Era are represented by the Cuddapah and Vindhyan systems, 1400–550 million years old. The Cuddapah system consists mainly of quartzites, sandstones, slates and limestones developed in Andhra Pradesh, Orissa and Madhya Pradesh. Roughly contemporaneous with the Cuddapahs is the Delhi system of slates, phyllites, metamorphosed limestones and quartzites exposed along the main axis of the Aravalli range from Delhi to Idar in Gujarat The system is intruded by granites such as the granite massif of Mount Abu (Pl 18) Pl 19 shows the Alwar quartzite belonging to the Delhi system The rocks of the Vindhyan system are more or less horizontally bedded sediments exposed over a large area in Bihar, Madhya Pradesh and Rajasthan The upper Vindhyans are generally considered to be of the Cambrian age.

Proterozoic Life

The Proterozoic Era was the age of simple organisms like algae and protozoa Myxophyceae, the slime algae, which possibly evolved from strains of bacteria, and like them lack nuclei, must have played a dominant role in this era These slime algae covered the bare Proterozoic rocks, and were perhaps the first land plants Along with bacteria



GRANITE MASSIF OF MOUNT ABU IN RAJASTHAN

It has weathered into fantastic forms Caverns and holes are produced by the removal of easily eroding materials. These rocks are over 800 million years old

[illegible] QUARTZITE

These rocks are pre-Cambrian and are over [illegible] million years old

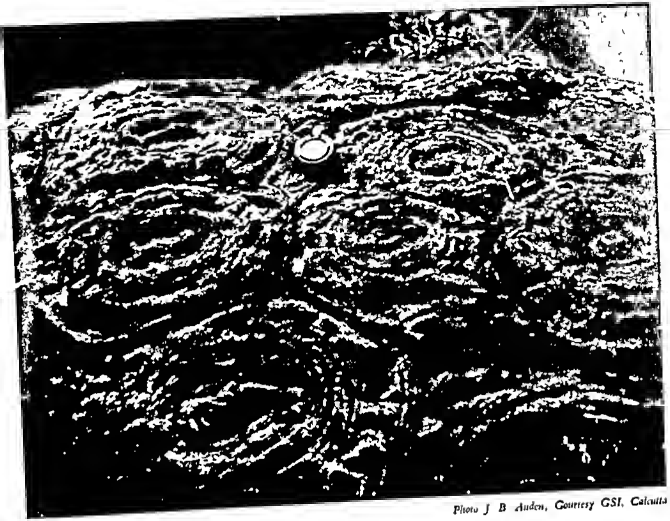


Photo J B Auden, Courtesy GSI, Calcutta

SPHEROIDAL FAWN LIMESTONE FROM THE LOWER VINDHYANS FORMED BY CONCENTRIC LIME REMAINS OF A GROUP OF THE PROTEROZOIC ALGAE

Courtesy Smithsonian Institution

IMPRESSION OF JELLY FISH, BROOKSELLA CANYONENSIS FROM THE PROTEROZOIC STRATA UNDER THE GRAND CANYON ARIZONA USA

they were the pioneer soil builders Late in this era, there was a deposition of iron compounds like haematite (Fe_2O_3) over the bottom of shallow seas, possibly due to bacterial action The iron ore deposits of USA, Brazil, and Sweden are regarded as organic in origin Calcareous masses deposited by algae (Pl 20), skeletons of Radiolaria, spicules of sponges, and worm tubes have also been found Unicellular calcareous flagellates and filamentous forms comparable to *Rivularia* and *Oscillatoria* are known from southern Ontario Life forms during this era were probably delicate and devoid of shells and harder parts and that perhaps explains the paucity of records Impressions of jelly-fish, *Brooksella canyonensis*, found from the Proterozoic strata under the Grand Canyon, Arizona, USA (Pl 21), are, however, significant in this respect Certain structures resembling vascular plant spores have been found in the Raipur area of Madhya Pradesh

BASIC STEPS IN EVOLUTION

Owing to the paucity of fossils in the Proterozoic, it is not possible to decipher the early steps in the evolution of life The abundant comparable life forms in modern protista and the other unicellular and primitive plants and animals do, however, point towards certain basic evolutionary trends as discussed below which might have characterized the pre-Cambrian life

Protista The primordial living beings like *Chlamydomonas* which combine both plant and animal characteristics and referred to 'Protista' by Haeckel were perhaps common in the Proterozoic seas *Chlamydomonas* has two hair-like appendages with the aid of which it moves about in water In this respect it can be called an animal, a flagellate member of the phylum Protozoa On the other hand, it also has a chloroplast containing chlorophyll Chlorophyll plays an important part in photosynthesis, the process by which complex organic substances are built up by plants from CO_2 of the air and hydrogen and oxygen of water It is plants alone which are able to feed at such an elementary level and *thus transform the kinetic energy of sunlight into the complex potential chemical energy* of foodstuffs like starches and proteins on which the animals feed Thus the possession of chlorophyll by some protista, of which *Chlamydomonas* is a living representative, is a chemical and physiological achievement of the highest order which made the life of plants possible and through them of animals including man

Divergence of plants and animals The protista lie at the base of the tree of evolution of life Neither clearly plants nor animals they indicate a stage of the parting of the ways between plants and animals which is one of the great steps in evolution May be the animals developed by loss of chlorophyll from the protista, on account of assumption of a more active life On the other hand, the plants developed from protista by loss of flagella, which led to a more passive existence As Patrick Geddes and

Arthur Thomson say, "The plant cell, by shutting itself up in a wall of cellulose, instead of fully oxidizing this substance, and perhaps also by less efficient elimination of nitrogenous waste, doomed itself to fixity and to sleep."

This great step in evolution, the divergence of plants and animals, perhaps took place early in the pre-Cambrian Eras. The tree of life forked out into two main stems, the plants and animals, which, with the lapse of time, divided and sub-divided into numerous branches.

Differentiation of cells. Primitive unicellular organisms, like Protozoa can be divided into *three groups: very active, moderately* active and passive forms. *Infusorians* like *Paramecium* and *Trypanosoma* represent the very active forms which swim about in water with the aid of hair-like appendages. At the other extreme are quiescent forms like *Gregarina*. Between the two are amoeboid forms which represent a compromise between extreme activity and extreme passivity (Fig. 19). These three forms which are noticed in the Protozoa are also seen among the cells of the higher animals. There are active ciliate cells, like the ciliated epithelium which lines our air passages. The amoeboid

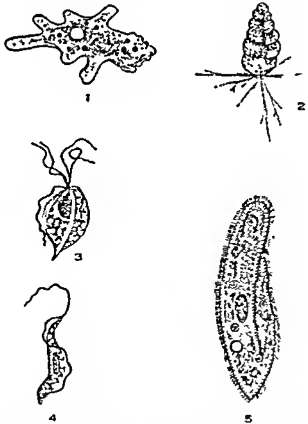


FIG. 19. SOME OF THE PROTOZOA SHOWING AMOEBOID, FLAGELLATE AND CILIATE FORMS: 1, Amoeba; 2, a foraminifer 3, *Trichomonas*; 4, a trypanosome; 5, *Paramecium* (1–4, after Schneider *et al*, 1963, 5, after Puri)

white blood corpuscles are comparable to amoebae In the skeletal, fatty and connective tissues can be seen the passive encysted cells The spermatozoon is flagellate, the young ovum is amoeboid, and the mature ovum is encysted The vegetative cells of plants are encysted, and flagellate and amoeboid phases are seen in their reproductive cells In some diseases we see the transformation of one type of cells into another, as in a kind of sore throat, the ciliated cells of the windpipe sink into an amoeboid phase The differentiation of cells has a physiological basis, the very active infusorian represents preponderant anabolism, the passive encysted forms represent preponderant katabolism, and the amoeboid forms represent a compromise between the two This differentiation of forms which is noticed in Protozoa and algae was one of the significant evolutionary advances and is of great importance among higher plants and animals, reflecting a division of labour among cells and tissues

Formation of body and beginning of death. The simplest organisms like Amoeba are single cells, which are physiologically complete in themselves Their common mode of reproduction is by fission or fragmentation, the single cell which represents the individual divides into two The parent individual becomes directly converted into its children Thus the unicellular organisms like Protozoa are immortal In cases like these, one can hardly speak of death when there is nothing left to bury. Unicellular organisms are not subject to natural death in the same sense as the higher animals They may be killed occasionally, but they do not normally die

Body formation arose from the weakness of daughter units, which instead of drifting apart coalesced into composite masses Thus in *Pandorina* the daughter cells do not drift away, the strength arose, the strength of the body, the strength due to unity While body formation led to higher organization and advance in life, this was achieved at a very high cost, death was the price paid for the body

Origin of sex. The formation of body was followed by another remarkable advance, the origin of sex We see the beginning of the innovation even in simple colonial forms like *Pandorina* which consists of sixteen similar cells held together by a gelatinous matrix (Fig 20) The protoplast of a cell of the colony divides into biflagellate gametes which are similar in appearance These isogametes fuse and produce a zygospore which by division and sub-division reproduces the 16-celled colony In forms like *Volvox*, where the free swimming colony is a hollow sphere consisting of hundreds of ciliate cells connected by strands of cytoplasm, we see another advance Some of the cells become eggs Some of the cells lose their cilia, and divide into a number of biciliate sperms, which fuse with the egg cells Thus, we see differentiation of germ cells from body cells A division of labour among the cells arises, the germ cells being differentiated from body cells This is an economical improvement in the starting of new life, and also saves the germ cells from the mishaps

which may befall the body It also affords opportunities for mingling of different characters in fertilization, and for new organic permutations and combinations, which eventually result in new forms.

Radial and bilateral symmetry, and formation of head and brain Another evolutionary advance of a radical type which took place possibly in the late Proterozoic Era was from radial to bilateral symmetry In most sponges, and coelenterates like *Hydra*, coral polyps, sea-anemones and jelly-fish, the body has a radial symmetry, that is to say, it can be cut into symmetrical halves along many different vertical planes, and there is no right or left Radial symmetry is well suited for animals like coral polyps which live in the uniform environment of the open sea, where all directions mean very much the same, and for animals which live a sedentary life like sea-anemones, and wait for food to come within the grasp of their tentacles Where an animal has to lead a more active and strenuous life, to chase the food, to flee from enemies, and to pursue mates, radial symmetry is unsuitable Flat worms, like *Planaria*, were the first two-sided animals with head and tail ends which took to crawling on one side only with one end always in front In earthworm, we see more advances in the same direction We see the development of head and tail ends, and differentiation of right and left sides The forms like earthworms, which mark the advance from primitive radial symmetry to bilateral symmetry, began moving with one part of the body always in front which became the head As the head end constantly received stimuli and impressions of external objects, it also led to the development of brain in the concentration of nerve cells in the form of ganglia, which became the anterior brain—the chief motor, sensory, and coordinating nerve centre of the body, ultimately culminating in the complex human brain

Blood and body cavity. The flat worms like *Planaria* have no circulatory system Lack of a blood system doomed them to flatness, for the body must be of necessity thin and flat, so that oxygen of the water could get in touch with tissues of the body This also led to branching of organs The innovation of coelome or body cavity and a blood circulatory system appears first in the roundworms Equipment with a blood system provided an opportunity for growth in three dimensions, and the organs became compact and solid, for blood could bring oxygen to all of them Body cavity or coelome provided a cushion for the internal organs like the intestine, and also made them independent of the outer body wall The fluid in the coelome with its numerous white blood corpuscles, provided a sanitary cordon for the protection of internal organs from harmful bacteria.

The mouth and the anus The roundworms had another improvement in their structural plan It is the acquisition of two separate apertures for the digestive tube, the mouth and the anus In sponges, there is no definite mouth, and intake of water which also contains food materials takes place through many holes In coelenterates like *Hydra*, we

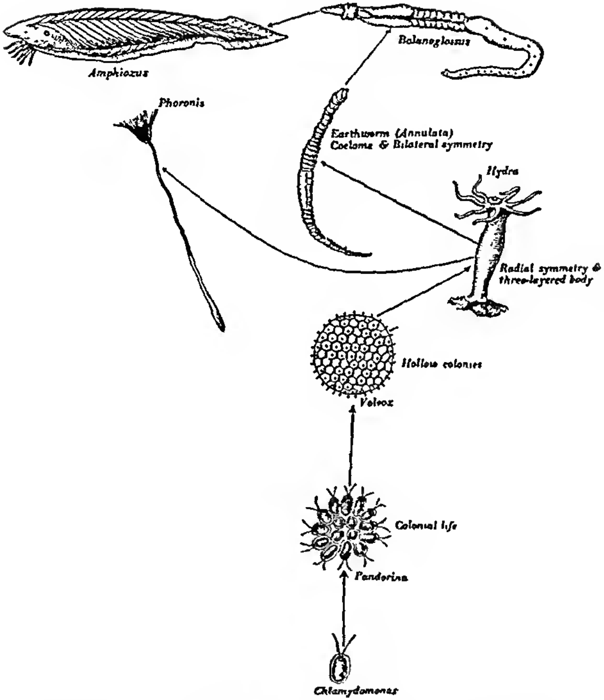


FIG. 20. PROBABLE BASIC STEPS IN THE EVOLUTION OF ANIMAL LIFE FROM UNICELLULAR FLAGELLATES TO EARLY CHORDATES

see a digestive cavity and a mouth for the first time. The mouth, however, also functions as an anus for the excretion of waste matter, and undigested food goes out by the same aperture through which the food is taken in. In roundworms we see mouth and anus at two ends of the alimentary canal. This enables the animal to feed continuously, and to have the original tube-like intestine specialized into a succession of regions, each with its particular function It is from worms with a bilateral symmetry, with definite head and tail ends, mouth and anus, coelome and blood vascular system, and central nervous system, that the higher groups of animals like molluscs, arthropods, and finally chordates arose. Some basic steps in the early evolution of animal life as discussed above are indicated in Fig. 20.

CHAPTER SEVEN

THE CAMBRIAN, ORDOVICIAN AND SILURIAN PERIODS

The Age of Marine Algae, Trilobites, Brachiopods and Cephalopods

THE EARLY Palaeozoic Era comprising the Cambrian, the Ordovician and the Silurian Periods includes the oldest rocks with fossiliferous strata The records of early Palaeozoic life forms are not only abundant but less effaced than those of the pre-Palaeozoic Eras, so that the steps in the evolution of life can be deciphered with some degree of definiteness and satisfiction

The oldest rocks of the Palaeozoic Era in the British Isles were first studied by two British geologists, Sedgwick and Murchison Murchison in 1835 applied the name "Silurian" to these rocks, recognizing their two-fold division—the lower and the upper Sedgwick referred the lower Silurian of Murchison to Cambrian after Cambria, an old latin name for a part of Wales Lapworth in 1879 named the lower portion of the upper Silurian as Ordovician after the ancient tribe, Ordovici, known from Wales This three-fold division of the oldest rocks of the Palaeozoic is now generally recognized, and is amply supported by physical and organic evidences Fig 21 shows the mountains of the Armorican-Hercynian system, constituting the rocks which were formed during the Cambrian Period

Early Palaeozoic Rocks in India

In India, the occurrence of the early Palaeozoic rocks is very much restricted to the extra-peninsular region The Cambrian rocks occur in the Salt Range in West Pakistan, in Spiti in the district of Kangra, and in the Baramula district of Kashmir The Ordovician and Silurian rocks are met with in parts of Spiti, and in parts of Kashmir, Hazara and the Simla Himalayas Pl 22 shows a succession of overfolded rocks in upper Lidar valley, Kashmir, ranging in age from Silurian to Triassic The early Palaeozoic rocks are mostly marine deposits comprising limestones, sandstones, quartzite and shales The Spiti area has become the classic ground of Indian geology and contains massive stratified deposits of the Tethys Sea which during the Cambrian and later periods covered the area now known as Tibet and Himalayas From its occurrence in the high snow covered peaks, the Cambrian system of rocks has been named as Haimanta

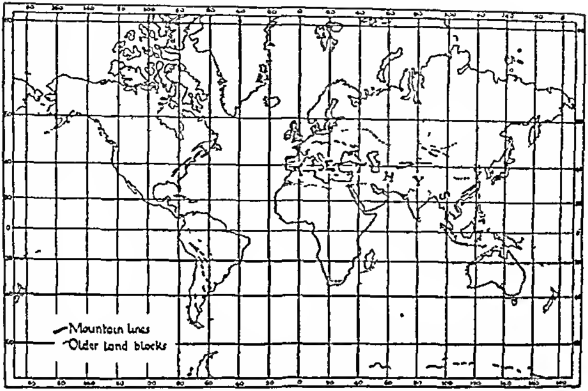


FIG 21 MAP SHOWING THE MOUNTAINS OF THE ARMORICAN HERCYNIAN SYSTEM FORMED DURING THE CAMBRIAN (After Harold Peake & Herbert John Fleure)

The Cambrian shales provide slates for school children, as well as roofing material for houses in the Himalayan districts These slates sometimes split into plates as thin as paper

A passing reference to a vast stratified formation of sandstones, shales and limestones over 4256 m thick in the Vindhyan mountains will not be out of place This formation of rocks is called the Vindhyan system It occupies over 104,000 sq km of the country from Sasaram and Rohtas in western Bihar to Chittorgarh on the Aravallis Some undoubted evidences of life, both indirect (limestone, carbonaceous shales, glauconitic sandstones lenticels of coaly matter, vitrain, etc) and direct (carbonized horny discs and fucoid markings), are probably indicative of the topmost part of the system belonging to the lower Cambrian Further, the upper Vindhyans are lithologically similar to the Cambrian purple sandstone of the Salt Range The absence from peninsular India of the deposits, constituting nearly three-fourths of the earlier Palaeozoic history, is indeed noteworthy.

Co rtesy GSI Calcutta

OVER-FOLDED ROCKS, SILURIAN TO TRIASSIC IN AGE, FROM THE UPPER LIDAR VALLEY, KASHMIR

PLANT LIFE

Algae

Algae belong to four main groups blue-green algae, the Cyanophyceae; green algae, the Chlorophyceae, brown algae, the Phaeophyceae; and red algae, the Rhodophyceae To whichever group they belong, with the exception of their calcareous members, they are all soft, jelly-like plants and have hardly left any fossils Some fossils assigned to algae, on closer scrutiny, have been found to be mineral deposits For instance, *Spirophyton*, which was described as a marine alga from Cambrian rocks, is now believed to be an inorganic deposit Outer form alone is not a safe guide for the identification of fossil algae and the internal structure is very rarely preserved As such, the relationship of the fossil forms with living genera of algae is hard to establish It is on account of this uncertainty that the name Protophyceae has been suggested for fossil algae.

From the upper Vindhyans certain algal forms, showing affinities with the Cyanophyceae, an alga belonging to the Dasycladaceae, and algal dust comprising minute spherical bodies, have been described Some objects looking like desmids have also been reported

Marine calcareous algae on the other hand have left fossils which are identifiable These algae played an important role in the formation of coral reefs in the Palaeozoic seas On account of their superficial resemblance to corals, some of them have been mistaken for animals *Solenopora*, now recognized as a close relation of *Lithothamnion*, a member of Rhodophyceae, was first described as an animal from Ordovician rocks in Estonia

The marine calcareous algae, recorded from Cambrian rocks, very much resemble the existing species of warm seas, and have persisted from the Cambrian Period onward with little change in general plan of construction *Girvanella*, discovered from Ordovician limestone in Scotland, is related to the family Codiaceae of the order Siphonales *Dimorphosiphon*, related to the genus *Halimeda*, is the oldest member of the family Codiaceae and has been discovered from Ordovician rocks of Norway.

Vascular Plants

Recent researches have revealed the occurrence of vascular plants during the Cambrian Some fragmentary shoots covered with microphyllous leaves have been found from the middle Cambrian of Aldan Mountain Range in Siberia Referred to as *Aldanophyton antiquissimum* Kryshtofovich, these are the earliest land plants known This evidence is supported by the occurrence of spores and tracheids with bordered pits in the Cambrian rocks of India, Sweden and USSR These evidences tend to show that the conquest of land might have taken place much earlier than the Silurian-Devonian, as has been believed until now.

Not much is known of the plant life during the Ordovician Some fern-like plants of very simple structure with profusely branched leafless stems have, however, been recorded from the lower Ordovician limestone in Wyoming

That much diversity had been attained by plant life during the Silurian is clear from such vascular plants as *Hedeia* and *Yarravia*, and a distinct lycopod *Baragwanathia* *Hedeia corymbosa* which also extends into the lower Devonian, is known from the upper Silurian of Australia All that is known of this plant is a terminal aggregation of dichotomously forking branches arranged in a corymbose pattern, each branch bearing ovoid bodies, probably sporangia The entire aggregation is three-dimensional in nature *Yarravia*, also from the Silurian of Australia, is an axis fragment bearing a terminal synangium of five or six sporangia

Baragwanathia longifolia is an undoubted lycopod known from the Silurian of Australia This plant had many characters in common with the modern *Lycopodium lucidulum*, although it was much larger in size The dichotomously branched stems had lax, slender leaves The reniform sporangia were associated with the ordinary leaves, but their mode of attachment has not been established The stem was traversed by a primary stele with annular tracheids

Prototaxites an enigmatic Silurian plant fossil, extended into the Devonian Its stem is made up of a matrix of intercalated filaments aligned throughout the length The larger filaments have much thicker walls than the smaller ones Besides there are uniformly spaced spots probably representing areas of specialized filament organization

The above mentioned early Palaeozoic terrestrial plants were perhaps the progenitors of the profuse land vegetation of the Devonian Period

ANIMAL LIFE

Invertebrates

The animal life known from the early Palaeozoic is marine, and almost entirely comprised various groups of invertebrates Fig 22 shows a Cambrian landscape with representative animal forms of the period and Pl. 23, a restoration of the Silurian sea bottom

Protozoa The Cambrian protozoans were foraminifers with shells of calcium carbonate Together with radiolarians with shells made up of silica the foraminifers abounded the Ordovician seas and continued to be present during the Silurian The early Palaeozoic protozoans have undergone the least evolution and they were very much like the modern marine forms

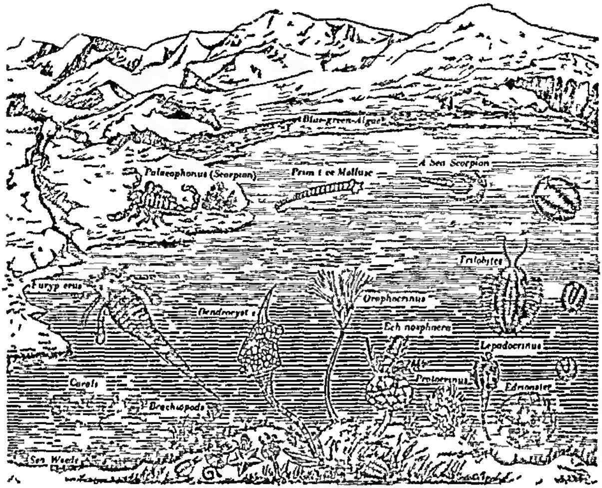


FIG 22. ANIMAL LIFE IN THE CAMBRIAN PERIOD The age of corals, echinoderms trilobites and scorpions. Land was bare and there was no vegetation excepting blue-green algae

Sponges Likewise the sponges have undergone the least evolutionary change Only those with hard skeletons have been preserved

Coelenterates The Cambrian corals resembled the sponges, but there were true corals too It is obvious they must have evolved from the sponges They became common during the Ordovician, and three types of them—the cup or horn corals the honeycomb corals and the chain corals—were present As distinguished from the modern corals which are hexacoralla or octacoralla with six or eight radiating partitions or septa, the early Palaeozoic corals were all tetracoralla in which partitions were four in number or in multiples of four They were rarely branched and had much larger polyps whereas the modern corals are profusely branched and have small polyps The simple cup corals

were dominant during the Ordovician but the compound forms superseded them during the Silurian Amongst the modern corals the compound or the colonial forms are more common than the solitary ones Jelly-fishes which are very delicate animals are also preserved in the Cambrian rocks

Bryozoans The Ordovician marine life abounded in the bryozoans, which were also reef builders They were very much like the modern forms and have shown the least evolution during the geological ages

Echinoderms Even in the early Cambrian, the echinoderms developed and differentiated into several groups The ancestral form of this group of animals was a two-sided worm-like creature which browsed slowly over the bottom of the sea This ancestor took to attaching itself to the bottom of the sea by its mouth Adhesive glands, and finally a stalk developed which served the function of attachment, while the mouth shifted away Adoption of sedentary life led to a reversion to radial symmetry New means of getting food by grooves lined with cilia to sift small particles of it from the water mouthwards were developed They also evolved an elaborate system of water-carrying tubes The tenaceous skeleton-armour was developed as a protection against the predatory arthropods of the period The Cambrian echinoderms were all fixed to the bottom *Echinosphaera* and *Aristocystis* were round animals attached by a short stalk *Dendrocystites* was a stalked animal with a single tentacle and food-groove *Edrioaster* was a box-shaped creature with the mouth on the upper side (Fig 22) A few fossil crinoids have also been recorded from Spiti With all their complicated structure, the echinoderms represent a blind alley of life They never evolved a head nor acquired a brain, and they never left the sea

Brachiopods The other important Cambrian fossils were the brachiopods Their horny shells or valves were not joined together by a hinge Those with shells joined together—the articulate forms—appeared towards the late Cambrian and they outnumbered the inarticulates in Ordovician One of the most remarkable survivors of the Cambrian Period is *Lingula* a brachiopod genus which is extant and has shown little change More than 10 per cent of the animals in the Cambrian seas were either brachiopods or trilobites and these two groups constituted the most important part of the Ordovician fauna

Molluscs During the Ordovician the pelecypods with hinged shells developed but unlike the brachiopods their shells were asymmetrical. The pelecypods gradually attained dominance over the brachiopods which gradually became almost extinct

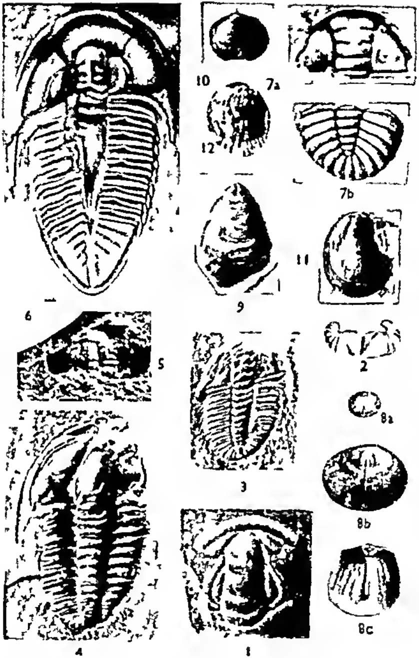
The animals with one chamber and a coiled shell, the gastropods made their appearance during the Cambrian increasing in later periods to thousands of modern forms without any conspicuous evolutionary changes

Courtesy Buffalo Museum of Science New York

A RESTORATION OF THE SILURIAN SEA BOTTOM

In the left foreground is a pair of crinoids on the reef are the cystoids which have arms and the blastoids which do not on the bottom mud are several kinds of trilobites long shelled squid ancestors (cephalopods) lamp shells (brachiopods) bryozoans a snail and corals

Pl 24



Courtesy GSI Calcutta

SOME CAMBRIAN ANIMAL FOSSILS FROM INDIA AND NEIGHBOURING COUNTRIES

1 *Redlichia noetlingi* (Redlich) 2. *Pseudotheca waageni* Redlich 3 *Oryctocephalus salteri* Reed 4 *Ptychoparia spitiensis* Reed 5 *Chittidilla plana* King 6 *Anomocare hundwarense* Reed 7a *Tonkinella kashmirica* Reed (cranidium) 7b *Tonkinella kashmirica* Reed (pygidium) 8a b & c *Neobolus warthi* Waag 9 *Lingulella spitiensis* Reed 10 *Acrotreta parahoen* Reed (brachial valve) 11 *Acrothele praecursor* Reed (pedicle valve) 12 *Acrothele vertex* Reed (pedicle valve) (1-7 trilobites and 8-12, brachiopods)

The many-chambered forms, the cephalopods, first appeared during the Cambrian and became relatively abundant in the Ordovician The shells in the Cambrian forms were of simple, straight or curved type like the *Orthoceras* and *Cyrtoceras* More curved forms, open coiled forms and closed coiled forms appeared during the Ordovician They were all characterized by straight or at least very simple septa or chamber partitions The close coiled nautiloids of the Ordovician are very much like the modern pearly nautilus, a living representative of the almost extinct nautiloids

Arthropods The trilobites were the dominant group among the arthropods of the Cambrian Period These extinct animals are considered primitive crustaceans and in all probability they had evolved from worm-like ancestors They were highly organized, with a distinct head-shield, a body, and a tail-shield Trilobites had a single pair of sensory feelers, and their hind appendages were constructed on the primitive forked plan characteristic of crustacean larvae None of the appendages were converted into jaws as in some of the present day arthropods They ranged in size from just short of one cm to 60 cm in length and exhibited different forms and modes of life They had developed many defensive devices and had eyes on the top of the head and could detect any enemy passing above Heavy chitinous armour acted as a protective outer covering and also provided a rigid leverage for the muscles It had another advantage, for it lends itself to jointing, and this helped in the evolution of jointed limbs The tough chitinous armour also made it possible for the successors of trilobites to emerge into air without risk of rapid desiccation

Trilobites were the most perfectly adapted products of the Cambrian world They increased in numbers and species during the Ordovician and developed odd and highly ornate forms with spines, tubercles and horns during the Silurian

Among other arthropods of the early Palaeozoic were the ostracods and the eurypterids (sea-scorpions) The eurypterids, rare in Cambrian, became common in Ordovician but attained dominance in Silurian Whereas the ostracods were minute two-shelled animals, the eurypterids had an elongated body with all the appendages coming off from the head and with a spine- or plate-like tail Some of them were 1 8 m long The genus *Limulus* is the only living gill-breathing representative of the eurypterids Amongst the definitely known air-breathing land animals from the Silurian are the scorpions

Some of the animal fossils of India and neighbouring countries from the Cambrian, Ordovician and Silurian Periods respectively, are shown in Pl 24, 25 and 26

Graptolites These slender, colonial organisms were common during the early Palaeozoic. They were enclosed in a horny sheath and floated in the open seas, usually far away from the shores Because of their wide distribution the buried sheaths of the graptolites at the sea bottom can be used to identify the beds of the same age in different parts of the world

The dendroids or net-like graptolites appeared at the close of the Cambrian During Ordovician, branched graptolites became one of the most abundant forms of marine life Graptolites were still abundant in the Silurian, but with the exception of dendroids, they practically disappeared by the beginning of the Devonian Dendroids died out during the early Carboniferous

The fossil remains of this extinct group make it difficult to state definitely what they were They have been commonly placed under coelenterates in the past, but later discoveries establish their relation, though remote, with the now unimportant Protochordata

Vertebrates

Certain primitive fish-like forms possessing scales and plates are known from the Ordovician These interesting creatures, the ostracoderms, are now believed to be the transitional forms between the highly evolved invertebrates and the primitive fishes They continued to be prominent in the Silurian

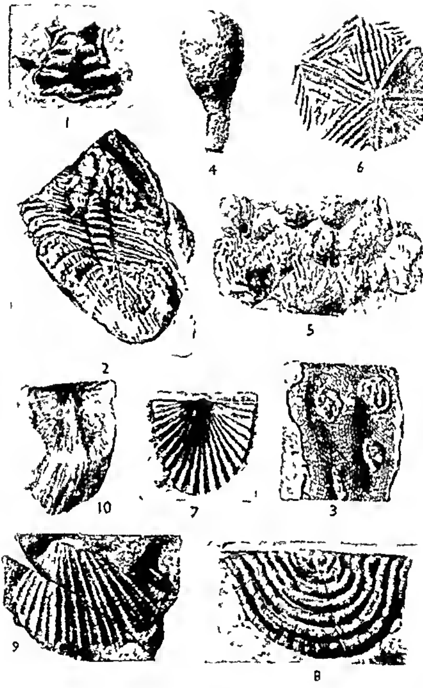
Evolutionary Trends in Early Palaeozoic Fauna

From the mere indirect evidence about the existence of life in the pre-Palaeozoic rocks to the definite presence of fossils of myriads of life forms in the early Palaeozoic is a great landmark in the evolution of life Far more interesting, however, is the conquest of land, for which some terrestrial animals, e g scorpions, provide the testimony Some of the life forms are fairly highly advanced, suggestive of their occurrence during the pre-Palaeozoic eras

The evidence of fossils during the early Palaeozoic helps to build up a continuous and progressive evolution of the various kinds of marine life from the simplest to the more complex The evolution of corals from sponges, of arthropods from worms, and the transitional nature of the ostracoderms between the arthropods and the fishes are some illustrative examples

The population of marine life during the early Palaeozoic periods varied in the types and proportions of the animals The Cambrian marine life was dominated by the trilobites and the next in order of abundance were brachiopods and gastropods Sponges and worms were common The hydrozoans and echinoderms were rare

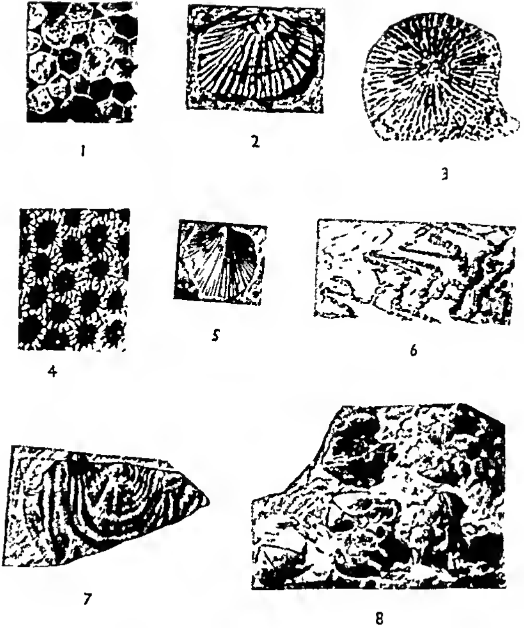
In order of abundance the marine life during the Ordovician comprised gastropods brachiopods bryozoans, trilobites, pelecypods, cephalopods and graptolites There was a great profusion of marine invertebrates of all kinds, showing besides great variety, considerable biological advancement Fish-like animals appeared for the first time during this period.



Courtesy GSI Calcutta

SOME ORDOVICIAN ANIMAL FOSSILS FROM INDIA AND NEIGHBOURING COUNTRIES

1, *Calymene nivalis* Salter, 2, *Oxygites birmanicus* Reed 3 *Graptodictya griesbachi* Reed 4 *Aparchites indicum* Reed, 5, *Aristocystis dagon* Reed 6 *Heliocrinus qualus* Reed 7, *Orthis pusulifera* Reed, 8, *Leptaena trachealis* (Salter), 9, *Pterinea thanamensis* Reed, 10, *Rafinesquina subdeltoidea* Reed (1-2, trilobites, 3, Bryozoa 4, Ostracod 5 & 6 Cystoidea, 7 8 & 10 brachiopods, 9, lamellibranch)



Courtesy GSI, Calcutta

SOME SILURIAN ANIMAL FOSSILS FROM INDIA AND NEIGHBOURING COUNTRIES

1, *Favosites spitiensis* Reed 2, *Orthis (Plectorthis) spitiensis* Reed 3, *Calostylis dravidiana* Reed, 4, *Stylaraea kanaurensis* Reed 5, *Orthis (Dalmanella) basalis* var *muthensis* Reed, 6, *Halysites catenularia* var *kanaurensis* Reed, 7, *Leptaena rhomboidalis* Wilckens, 8, *Pentamerus oblongus* Sow (1, Actinozoa, 2, 3, 5, 7 & 8, brachiopods; 4 & 6, corals)

The marine population during the Silurian Period was largely characterized by the decline of graptolites and trilobites and a considerable increase in corals, echinoderms especially crinoids and preponderance of brachiopods

Based on the distribution of various types of animals, the prevalence of faunal provinces during the early Palaeozoic has been recognized Local differences in faunal population also existed The Cambrian fauna from Hundawar in the north-west extremity of the Kashmir valley shows no affinities with the adjacent local faunas from the Salt Range, Spiti or the Persian Gulf The Hundawar Cambrian fauna was more akin to that of Indo-China

The evolutionary features within each group of animal fossils have been reviewed above Some of these facts seem to be of considerable significance After attainment of highly specialized forms, a general decline of the trilobites, the screw-shaped, spiral-shelled cephalopods and of graptolites, took place Several others, however, showed progressive evolution into complex forms, but some like the protozoans, the sponges, the bryozoans, the gastropods and the close-coiled Ordovician nautiloids have persisted to the present through all these millions of years without any conspicuous evolutionary changes

By the close of the Cambrian, most of the phyla of the animal kingdom had been established The pace of evolution, which probably had been slow eatlier, accelerated, possibly due to the introduction of free oxygen on account of the photosynthetic activity of green algae

CHAPTER EIGHT

THE DEVONIAN PERIOD

Evolution of Land Plants and Fishes

THE NAME Devonian is derived from the county of Devon in England because it was there that the rocks of this age were first described by pioneer geologists The Devonian Period had a span of about 45 million years and ended about 285 million years ago The configuration of earth was markedly different in this period and the large southern continent of Gondwanaland which consisted of Australia, peninsular India Madagascar, South Africa and South America stretched south of a vast sea, the Tethys which separated it from the two northern continents the North Atlantic Continent and the smaller continent of Angaraland. North America and northern Europe were linked together as is borne out by the distribution of marine animals (Fig 23)

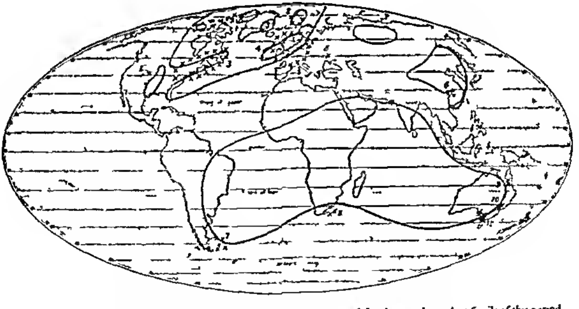


FIG. 23. MAP OF THE WORLD DURING THE DEVONIAN PERIOD Crosses mark localities where plant fossils of this period have been found. The shaded part represents water (Courtesy P Lake)

Devonian Rocks

In the Devonian system are included rocks of many kinds red sandstones, conglomerates, shales, and sediments containing fragments of terrestrial plants along with fossils of strange armoured fishes and gigantic crustaceans The series of rocks described from Devon is marine in origin, while the other series, which is found in Scotland, consists of thousands of feet of sandstones, shales and pebble-beds, and is called Old Red Sandstone Devonian strata do not occur at all in the peninsular India, and are restricted to the northernmost zone of the Himalayas abutting on Tibet, extending from Hazara and Kashmir, through Spiti, Garhwal and Kumaon to Nepal and upper Burma On the Muth pass in Spiti is found a thick hard series of white quartzite containing fossilized shells of a brachiopod, *Pentamerus oblongus* Muth quartzite with an overlying group of hard siliceous limestones, is also found in the neighbouring locality of Bushahr

Landscape

The Devonian landscape was barren and arid Ranges of pre-Cambrian mountains provided a bleak background for mounds, ridges, and slopes covered with sand and gravel In the sand dunes, smoking fumaroles, manifestations of volcanic activity of the young earth, could also be seen The desert conditions in Devonian Period were possibly not so much due to lack of rain as due to lack of soil on barren rocks, which were yet awaiting to be clothed with a protective covering of vegetation Hence, the Old Red Sandstone deserts of the Devonian were biological, rather than climatic The sea shore was covered with marine red, blue-green and green algae On the ground were found slender representatives of Psilophytales, like *Rhynia*, *Hornea* and *Asteroxylon*, hardly 15–50 cm high These plants carpeted the land as uniform green, relieved by brown tints of dead and decaying herbage They were among the first conquerors of land and prepared the way for higher plants and animals Fig 24 shows a Devonian palaeoscape with early land plants and animal life in water But for the shrieking winds and fitful breezes, it was a silent world with no cries of birds, or howls of mammals to enliven it.

Climate

Conclusions concerning the climate of the Devonian Period are based largely on the distribution of sea animals in that period Reef-forming corals which are now denizens of warm tropical waters were then found in the north polar regions indicating a rather uniform temperature of sea water at that time

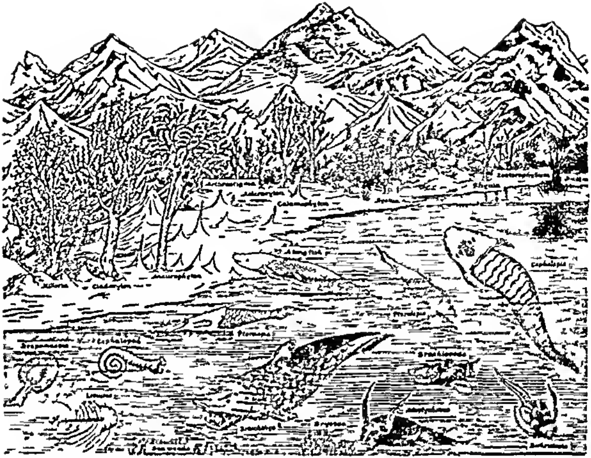


Fig. 24 A Devonian palaeoscape showing early land plants and the life in water. Fishes became predominant

PLANT LIFE

Origin of Land Plants

How did the land plants evolve from the primitive algae, which were the denizens of the sea and fresh water? Various explanations have been given of this transition One of the popular theories about the mode of origin of the land plants which gained recognition and was widely discussed is that of Church He assumes the existence of a universal sea, and emergence of land in the form of a number of islands, which became bigger and bigger till they formed continents As portions of the earth's crust emerged in the form of islands from the universal sea in the early geological history, marine algae which had reached a comparatively advanced state of organization, and were anchored on the rocks were exposed to the air at regular intervals as the tides receded Some of these, which were able to adjust their structure and mechanism to meet the changed environment, thus became the precursors of the first land plants

There are far too many assumptions in Church's hypothesis The existence of a world ocean with continents formed by small islands emerging out of it is one of such assumptions It has, however, been proved that when the Silurian ended considerable mountain building activity took place, continents were raised, and water surface shrank. It was a period of stress and struggle, and the seaweeds which were adapted to the uniform environment of sea water were exposed to the vicissitudes of existence on sea shores, and in salt marshes and freshwater swamps There is every likelihood that the actual transmigration of sea plants to land took place at the close of the Silurian and beginning of the Devonian times as evinced by the Silurian *Prototaxites* Fresh discoveries, such as *Aldanophyton*, have, however, revealed that the conquest of land may have already been achieved in the Cambrian

Despite our knowledge of the earliest land plants, we are still ignorant of the way they originated from algae In the progressive march of life, it has been seen that it is not the specialized forms of life, like elaborately built seaweeds which provide material for evolution On the other hand, it is the simpler generalized forms, plastic in structure, which evolved into higher forms of life, while more specialized forms became extinct It is probable that the ancestors of the first land plants were humble microscopic green algae, which took to land life Forms like *Fritschiella* have an elaborate, branched subaerial system, and a subterranean rhizoidal system The green cells of the subaerial system, like the leaves of the higher plants, manufacture food material with the aid of chlorophyll, while the rhizoidal system serves the function of storage of food material and of fixation and support Fig 25 shows the course of evolution of a complex alga like *Fritschiella* from unicellular motile forms like *Chlamydomonas* *Fritschiella* grows on wet mud near drying ponds or puddles From forms like *Fritschiella* to liverworts, which live in a similar environment, is a long stride in the evolution of plant life. No fossil records are available to provide any link in this gap The study of some of the highly organized extant liverworts, such as *Anthoceros*, however, throws significant light on the evolution of land plants

Anthoceros shows a distinct alternation of generations The sexual generation or gametophyte is represented by a creeping plate of green tissue called the thallus, which is lobed and wavy The sex organs are borne on the dorsal side of the thallus The male sex organs, the antheridia, are embedded in the thallus, and produce a number of sperms The female sex organs, the archegonia, are flask-shaped, and each contains an egg cell Sperms when liberated from the antheridia swim about in water on the surface of the gametophyte and fertilize the eggs From the fertilized egg develops the asexual generation called the sporophyte. The mature sporophyte or capsule of *Anthoceros* is an elongated structure embedded in the gametophyte by a bulbous foot. The projecting

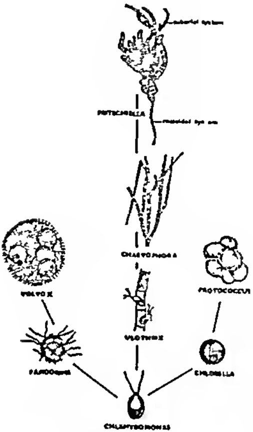


FIG. 25 EVOLUTION IN GREEN ALGAE. From un cellular motile forms like *Chlamydomonas* arose filamentous forms like *Ulothrix* Branched algae like *Chaetophora*, are the next step It is from such algae that complex algae like *Fritschiella* evolved and colonized the land

portion contains a central axis of sterile tissue surrounded by a layer of sporogenous tissue, which produces the spores Surrounding the sporogenous tissue are layers of sterile vegetative cells The outermost epidermal layer consists of narrow elongated cells containing stomata similar to those of higher plants The layers below contain chlorophyll with the aid of which the sporophyte is able to manufacture its own food material. Thus, in the sporophyte of *Anthoceros* we see the full equipment of a land plant, only awaiting its liberation from the gametophyte and ready to establish itself as a full fledged independent plant on the land (Fig 26)

Psilophytes

From the viewpoint of origin of land plants an interesting group of plants the Psilophytales, is characteristic of the Devonian Period. The lower Devonian

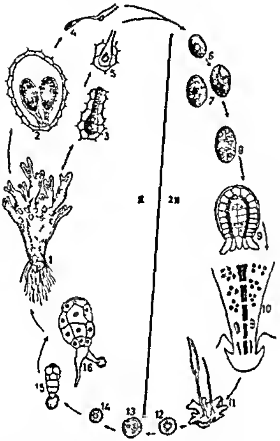


FIG 26 LIFE CYCLE OF THE LIVERWORT *Anthoceros* 1 Gametophyte 2, antheridia 3 & 5 archegonia 4 antherozoid 6-10 sporophyte 11 sporophytes embedded in the gametophyte 12, spore 13-16 germination of the spore and development of the gametophyte

Psilophyton princeps was characterized by leafless trailing dichotomizing shoots, probably rhizomes, with upright spiny dichotomizing axes bearing terminal sporangia The spines were short, occasionally with dilated tips but devoid of any vascular strand or stomata as present in the stem In some other species of the genus, the stems were sparsely clothed with appendages

Many middle Devonian representatives, such as *Rhynia gwynne-vaughanii*, *R. major*, and *Horneophyton*, were characterized by dichotomy, *Asteroxylon*, however, had monopodial shoot system *Asteroxylon* had a stellate vascular bundle and bore cuticularized leaves but the others were devoid of any appendages (Fig 27) Sporangia were simple except in *Horneophyton* which had columellate sporangia In contrast, *Taeniocrada dechenіana* had a ribbon-shaped shoot system which was dichotomously branched and traversed by a single strand, it bore terminal sporangia Closely resembling the fossil Psilophytales are the present day Psilotales represented

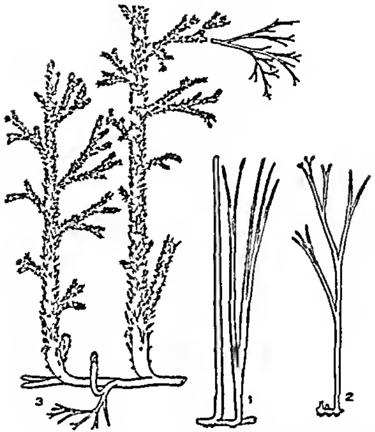


FIG. 27 EARLY LAND PLANTS 1 *Rhynia gwynne-vaughani* 2, *Rhynia* (*Horneophyton*) *lignieri* 3 *Asteroxylon mackiei* These plants were discovered from Red Cherts in Scotland (From Kidston & Lang)

by the genera *Psilotum* and *Tmesipteris* *P triquetrum* is found in the evergreen forests of the Western Ghats in South India (Fig 28)

From the sporophyte of *Anthoceros*, as described above, to fossil Psilophytales like *Rhynia* and *Hornea* is not a very big transition *Rhynia* and *Hornea* are so generalized in *their structure, that they have been placed with algae, mosses, or ferns They were erect* land plants, 10 to 20 cm high, with neither roots nor leaves Their spores were produced in swellings, at the ends of some of the forking branches, which were without any special arrangements for dehiscence as in ferns. Nevertheless, these simple plants were well equipped for life on land as is evident from the revolutionary structural advances they had developed, like stomata, lignin, vascular system and thick-walled spores The stomata interrupted the continuity of the surface layer, and as in higher plants regulated gaseous exchange with the outer air It was through the myriads of these little pores that carbon dioxide from the air was brought in contact with the chlorophyll.

A land plant is protected from desiccation by an outer layer of waxy covering, and many layers of cells turned into protective cork or bark. A land plant must carry its own weight, for it is no longer supported by a watery medium like an alga growing in water. This support in land plants is provided by cells which have died after loading their walls with lignin, a heavy deposit of woody substance. Columns of such cells strengthened with lignin provide a strong and flexible skeleton for land plants. Another necessity of a land plant is the vascular system. Some of the higher seaweeds have leaf-like structures joined to a hold-fast with a rudimentary stem containing an elementary transport system in the form of sieve tubes. Carbohydrates manufactured in the leaves have to be transported downwards to the stem and roots where they are often stored. Sieve tube cells serve for this downward transport, they remain alive and their protoplasm actively passes the food along. Unlike a seaweed, a land plant must get its supply of water and mineral salts from the soil, and for this purpose it must have a root system. For the transport of

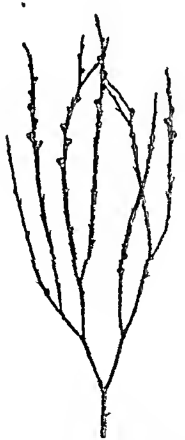


FIG. 28. A LIVING FOSSIL PLANT WHICH HAS A CLOSE RESEMBLANCE WITH THE DEVONIAN PLANTS—*Psilotum triquetrum* FOUND IN THE EVERGREEN FORESTS OF THE WESTERN GHATS, SOUTH INDIA

water and mineral salts, a system of tubes known as xylem is developed. This system developed from empty cells which communicate with each other by diffusion through thin places in their walls called pits, or coalesce end to end to form long microscopic tubes Like an India rubber hose-pipe with a spiral of steel wire, the xylem tubes are strengthened by rings or spirals of woody material. This type of vascular system had developed in *Rhynia*, the axial region of which is occupied by a cylindrical strand of woody tubes surrounded by a zone of more delicate tubular cells both forming together the conducting tissue.

The other genus of Psilophytales, namely *Asteroxylon*, is more advanced in structure The underground stem bears erect branching shoots clothed with small overlapping leaves like those of *Lycopodium* and associated with these are slender, naked forked branches bearing terminal sporangia, as in other Psilophytales Thus, in *Asteroxylon* we have a connecting link between the Psilophytales and the Lycopodiales Whereas small-leaved forms like Lycopodiales originated from forms like *Asteroxylon* and culminated in giants like *Lepidodendron* and *Sigillaria* forms with spreading fronds like *Aneurophyton* were possibly derived from a plant like *Psilophyton* whose simple lateral branches expanded into frond-like structures

Associated with *Psilophyton* there were plants characterized both by dichotomy and trichotomy and with clustered sporangia, such as *Trimerophyton robustius*

In the dichotomously forking, leafless shoot system of *Zosterophyllum*, the sporangia were borne in spikes The spike in *Bucharia ovata* had two rows of sporangia A combination of monopodial and dichotomous forking is seen in *Pectinophyton* the spikes of which bore two rows of ring-like appendages each enclosing a flat sporangium *Gosslingia breconensis* had sporangia scattered along the branch system of the axis, the tip of which was circinately coiled These complex forms are known from the lower Devonian.

Besides, there also existed certain thalloid forms, such as the early Devonian *Nematothallus*, about 6.5 by 1 cm and 2.5 cm fragments of a larger plant. The fragmentary thallus was made up of a reticulum of fine tubes, the larger amongst them having annular thickenings The slender tubes formed a close network towards the outside They were unique in being unspecialized in early stages for establishment in a land environment. There were some other curious upper Devonian plants Protosalvinias were disc-shaped bodies whereas *Foerstia* was dichotomously forked.

Quite in contrast with the Psilophytales some megaphyllous plants such as *Platyphyllum, Cyclopteris, Ginkgophyllum, Psygmophyllum*, etc. are also known from the lower to the upper Devonian. Though unrelated they possessed large fan-shaped elongate leaves

Enigmophyton was about a metre or more in length The lateral branches of its smooth stems bore sharply dissected fan-shaped leaves attached by a narrow base. The associated

fructifications were bifurcating spikes bearing several sporophylls, each having a sporangium in its axil Some sporangia had megaspores, where as others produced microspores

Protopterids and Progymnosperms

Some advanced types of psilophytes which had achieved distinction between stem and leaf are referred to Pre-ferns or Protopterids and those with secondary wood as Progymnosperms. The middle Devonian *Svalbardia polymorpha* had three-dimensional monopodial branching Leaves consisted of simple appendages which were usually dichotomously forked They were mostly filiform, but some were laminate Long, nearly cylindrical, stalked sporangia were borne on opposite ultimate divisions of the fertile branches The upper Devonian *Archaeopteris* bore pinnate leaves with entire, lobed or fimbriate pinnae *A. latifolia* was distinctly heterosporous (Fig 29)

Rhacophyton had a stout stem The sterile fronds had two rows of pinnae which in turn bore two rows of pinnules, each dividing dichotomously and without any appreciable lamina. The fertile frond also had two rows of pinnae, each forking from its base and then dividing into secondary pinnae or pinnules Each pair of pinnae,

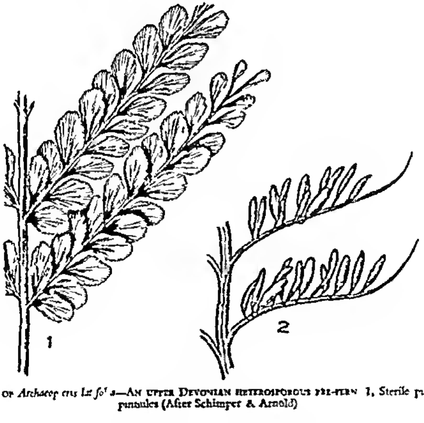


Fig. 29 Fronds of *Archaeopteris latifolia*—An upper Devonian heterosporous pre-fern 1, Sterile pinnules 2, fertile pinnules (After Schimper & Arnold)

either in the middle or upper portion of the fertile frond, formed a profusely dichotomizing branch system on its under side. Sporangia were borne on this branch system. Besides, there were plants looking like tree ferns, such as *Eospermatopteris*, *Aneurophyton* and *Tetraxylopteris*. The last two bore sporangia in clusters and had secondary wood in the rachis and main axis. *Eospermatopteris* attained a height of 12 m or so and was the tallest of these (Fig. 30). Its fronds were fern-like, and some of these bore terminal ovoid sporangia.

Cladoxyla

Another curious type of plant life was represented by small stem fossils. Stelar system in these was made up of several steles radiating from the centre. *Cladoxylon scoparium* bore two kinds of appendages, forked and fan-shaped.

Lycopods

Amongst the middle Devonian lycopods, *Drepanophycus* had *Lycopodium*-like habit with a creeping stem producing upright dichotomously forked shoots attaining a height of about 45 cm. The shoots had stout spiny appendages, some bearing a single sporangium on their upper surface. In the lower Devonian *Sugambrophyton* and *Protolepidodendron*, the leaves were forked, the sporangia were radially elongate and the stems had a triangular protostele. Leaves in *Colpodexylon* were three-lobed. The Devonian lycopods were largely herbaceous in habit, except *Stigmaria*, known from the upper Devonian of Bear Island between Spitzbergen and the North Cape of Norway. The upper Devonian *Archaeosigillaria* combined the characters of *Sigillaria* and *Lepidodendron*.

Articulates

Some lower Devonian unbranched shoots referred to *Protohyenia* bore appendages that forked several times. The oval sporangia were borne singly on the tips of forked branches. The *Calamophyton* of the middle Devonian had digitately divided main axis with the individual branches having monopodial or a mixture of monopodial and dichotomous branching. The appendages on the ultimate branches were three-dimensional, slender and dichotomously divided. They showed a tendency towards a whorled arrangement. Sporangia were slender and borne in pairs on lateral branches. The axes of *Hyenia vogtii* produced slender lateral branches, which bore leaves in fairly regular verticils.

Advances in Plant Life

From the meagre evidence of plant life in Silurian to a variety and diversity of plant fossils in the Devonian is a great step in evolution. Although some elements of Silurian

FIG 30 RESTORATION OF *Eospermatopteris* FROM THE UPPER DEVONIAN OF EASTERN NEW YORK (From Goldring Courtesy New York State Museum and Science Service)

flora such as *Prototaxites*, *Cooksonia* and *Hedeia* continued their existence during the Devonian and a few Silurian lycopods were followed by some more, the Devonian plant life was characterized by several kinds of new plants, some of which are clearly defined as the precursors of lycopods, articulates, ferns and gymnosperms It is from the Silurian-Devonian plant life, rather more from the Devonian itself, that it is possible to recognize the emergence of different lines of evolution An easily discernible march of evolution of plants, in fact, commences from this period

Several evolutionary trends are exhibited by the Devonian plant life emanating several lines of evolution the manifestations of which were found in the succeeding periods. From the plants like *Nematothallus* in its early attempts for the struggle to establish on land to distinct land plants of simplest construction, the prevalent dichotomy and its modification into monopodial system of branching, the origin of leaves and their development from microphylly to megaphylly and ultimate evolution into the pinnate leaves, the

evidences of homology between stem and leaf, the evolution of a single stele to polystelic condition (Cladoxylales) and a tendency towards whorled arrangement of leaves and branches as in *Calamophyton* and *Hyenia* are some important advances in the evolution of the vegetative characters shown by the Devonian plants Likewise, the evolution of terminally borne single sporangia to their clustering as in *Trimerophyton* and *Aneurophyton*, and highly evolved arrangement into spikes as in *Zosterophyllum* and *Enigmophyton* and development of heterospory are indeed great advances in the evolution of plant life. In this context the evolution of arborescence as in *Aneurophyton* and *Eospermatopteris* amidst an overwhelming herbaceous habit is an important progressive step in evolution

Of these diverse forms of plant life, some, however, clearly help us to follow up the evolution of lycopods, articulates ferns and gymnosperms which in the succeeding periods are present in abundance and exhibit considerable specialization Some like *Archaeosigillaria* are the transitional forms to later diversified plant life They combine the common features of *Sigillaria* and *Lepidodendron*

Thus, we find that before the close of the Devonian Period, a vegetation in which most of the major groups of the plant kingdom were represented had colonized vast areas of earth's surface (Pl 27) With the conquest of land, proliferation of plant life in a new environment, soil, which is largely a product of plant action, took place As Wells and Huxley describe, "Plant life, like human civilization has gradually extended its boundaries Under the pressure of the struggle for existence, its beneficent exploitation of the sun's energy has gradually enriched the world, softened its contours and its climate and reduced the extent of its waste spaces And since the plants opened the door to the animal invasion, their invasion of the land was a necessary pre-requisite to human evolution "

ANIMAL LIFE

Reef-building corals, echinoderms, brachiopods, molluscs, and trilobites and other arthropods of the early Palaeozoic fauna were abundant in the seas during the Devonian Period Devonian was, however, essentially the "Age of Fishes" and various types of them ruled supreme (Pl. 28) Fossils of some of the other animals of the period from India and neighbouring countries are shown in Pl 29

The clothing of land near the sea shore with green plants created a new source of food supplies on land The first animals to invade the land were *scorpions millipedes* and spiders, all members of the phylum Arthropoda These probably migrated from sea to the freshwater lakes, and from there to the land.

Painting Charles R. Knight. Courtesy Chicago Natural History Museum

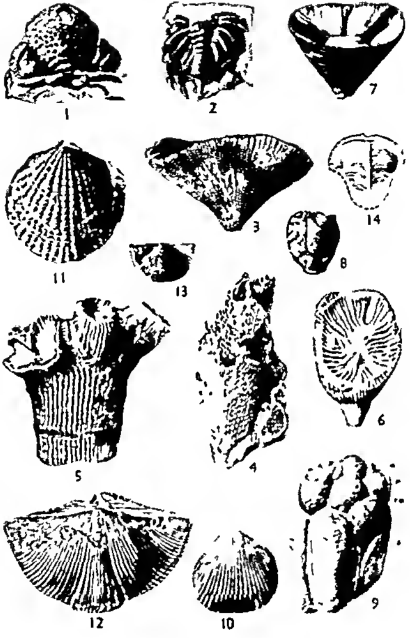
A DEVONIAN LANDSCAPE

Archaeopteris the world's oldest known tree is shown in the middle, a primitive tree like seed fern *Eospermatopteris* is on the right, spore bearing arthrophytes or horsetail rushes and psilophytes with curled tips are in the foreground

Courtesy American Museum of Natural History New York

FISHES OF THE DEVONIAN AGE FROM THE OLD RED SANDSTONE, SCOTLAND

Pl. 29



Courtesy GSI Calcutta

SOME DEVONIAN ANIMAL FOSSILS FROM INDIA AND NEIGHBOURING COUNTRIES

1 *Phacops latifrons* (Bronn) 2, *Dalmanites (Asteropyge) kotaghensis* Reed 3 *Hemitrypa oculata* Phillips 4 *Polypora hundletonis* Reed 5 *Cyathophyllum (Thamnophyllum) multizonatum* Reed 6 *Aulacophyllum Ingbiense* Schluter 7 *Calceola sandalina* Lamarck 8 *Storthingocrinus fritillus* (Wirtgen & Zeiler) 9 *Bactrocrinus birmanicus* Reed 10 *Lacinula var transiens* Reed 11 *Atrypa spinosa* Hall var *chitralensis* Reed 12, *Spirifer verneuili* Murchison 13 *Chonetes sublamellata* Reed 14 *Bellerophon shanensis* Reed (1 & 2 Trilobita 3 Hemitrypa 4 Bryozoa 5-7 Actinozoa 8 & 9 Cystoidea 10-13 Brachiopoda 14 Gastropoda)

Origin and Dominance of Fishes

From worms to fishes is a long stride in the evolution of animal life. Between the worms and the fishes numerous transitional stages can be seen *Balanoglossus*, the acorn-worm provides a link between the worms and the chordates This worm-like creature which burrows in mud has gill-slits, a small notochord and a rudimentary nerve cord These are all characteristic of chordates There is another group of animals called urochordates in which the notochord appears only in the tail of the larva which is free-swimming Such larvae are found among sea-squirts, and have a notochord and a rudimentary tubular nerve cord These tadpole-like larvae attach themselves to rocks by their mouths and become permanently fixed, lose their tails and are transformed into potato-like creatures

At a higher level are organisms like *Amphioxus*, a pre-vertebrate which provides the basic pattern of chordates, seen in a refined form even in the highest of vertebrates, man himself *Amphioxus* is a small fish-like creature found in abundance along the sea-shore near the mouths of the rivers of China and is used as food by the Chinese *Amphioxus* has the appearance of a surgeon's lancet and is about 5 cm in length It is compressed at the sides, and tapers at both ends It possesses an axial skeleton in the form of a gelatinous rod, called the notochord above which is a tubular nerve cord, which foreshadows the spinal cord of the vertebrates It is provided with segmental muscles which help in the propulsion of the animal through the water, and the pharynx is provided with numerous gill-slits It has a dorsal fin that runs the length of the body and a tail-fin Thus, this creature has all the major characteristics of a fish However, excretion takes place through nephridia similar to those of earthworm

A fossil animal allied to *Amphioxus* which has been named as *Jamoytius* has been discovered from the upper Silurian rocks of Scotland It is 15 to 18 cm in length, tubular in shape and has a flattened head bearing large circular eyes It has two fin folds at the sides, one on the upper surface, and the fourth, the anal fin at the posterior end The segmental pattern of the muscles as well as the notochord is clearly seen

It is from animals like *Amphioxus* and *Jamoytius* that the fishes arose, possibly in the late Ordovician or early Silurian This remarkable change possibly took place in the fast running freshwater streams It is noteworthy that the earliest fishes are found in freshwater sediments of the Ordovician Such remarkable body changes could only be stimulated by a dynamic environment, such as that of fast running freshwater streams which made a greater demand on the animal The static environment of the sea, with abundance of food in the form of plankton which would reach the mouths of the creatures fixed on rocks submerged in the water of the oceans, could not have stimulated body changes, such as bilateral symmetry, segmental muscles, axial skeleton in the form of a notochord, and a centralized nervous system represented by a hollow nerve cord

Fishes of various kinds were represented in the Devonian Period, and that is why it is called the "Age of Fishes" (Pl 28) Armoured limbless fishes, called ostracoderms, were very common Some of these were studded with denticles, some had armour of mosaic plates, while others had wonderful head-shields like the present day cyclostomes The number of gill-slits in ostracoderms had not been reduced to five pairs as in modern bony fishes, and there was no jaw, as the first gill-arch was still a gill-arch. Some of these ostracoderms are in such a fine state of preservation that even the anatomy of a few forms has been worked out Like the present day dogfish or a skate, the ostracoderms had a skin covered with denticles These denticles had the same structure as a tooth, with enamel, dentine, pulp-cavity and the rest, anchored in the skin by a little expanded base. These fishes, though they lacked proper teeth in their mouths, had scattered them all over their skins The teeth, we possess, are in all probability elaborations of these denticles of fishes, enlarged and improved in design, and socketed into jaws

Another group of fishes which attained *prominence in* the Devonian was the armoured, joint-necked fishes, which had ball and socket joints between the skull and armour plates on the back. Some of these fishes were as much as 7 5 m long and were giants of the Devonian seas However, they became extinct by the close of the Devonian, thus illustrating the well known law of evolution, that over-specialization, heavy armour-plating, and giant size ultimately lead to the extinction of the species

Fishes resembling modern sharks also flourished in the Devonian They had real jaws and efficient paired limbs in the form of two fins on each side of the body These fishes had cartilaginous skeleton which was by degrees replaced by bones It is, however, in the bony fishes that we see bone harder, stiffer, and more efficiently built, replacing the flexible cartilage Bony fishes, which are the dominant group today, had humble ancestors in the Devonian

Lung-fishes Amongst the varied array of fishes in the Devonian was a group, known as Mud-fishes or Lung-fishes which held promise for the future These lung-fishes are represented today by three genera which are found in three different continents *Lepidosiren* in South America, *Neoceratodus* in Australia, and *Protopterus* in South Africa. This type of discontinuous distribution of freshwater fishes is also an evidence of the contiguity in the Devonian Period of these three continents in the form of one land block, Gondwanaland, which formed an extensive southern continent. In a very striking manner, land links and land connections of the past are indicated by these three genera of fresh-water fishes which are at present found in three continents isolated from each other by long stretches of ocean The lung-fishes had two advances over other fishes, viz. paired limbs and swim-bladders which function as lungs Fishes live in water, and get their oxygen through their gills from water They also possess a balloon-like sac filled with air, called

the swim-bladder which renders the fish relatively lighter than water. The swim-bladder helped in the liberation of animals from sea water and enabled them to conquer land The streams in which lung-fishes live are choked with vegetation during the rainy season, and become chains of stagnant puddles in the dry months Thus, it is a very difficult environment for ordinary fishes, who get choked and die The lung-fishes have, however, been able to survive in these stagnant puddles, by the aid of their swim-bladders which function as an auxiliary lung, and by means of which they breathe oxygen direct from air The Devonian was an age of stress and struggle Due to tectonic activity earth was elevated, and many lakes and lagoons were formed During severe droughts, which were characteristic of this period, a large number of freshwater fishes were exposed to the danger of extinction While many died, some retreated to the ocean and a few evolved primitive lungs and limbs Flexure in the forelimbs of *Lepidosiren* indicates the manner in which the paired fins of a fish slowly became transformed into the limbs The elongated paired fins became transformed into a sort of legs without feet, enabling the animal to crawl along clumsily over the earth's surface

Periophthalmus, a fish which is found in the rivers of tropical Africa, climbs trees with the aid of its modified fins and is said to walk faster than man *Sauripterus*, an upper Devonian fish, had bones in its fins which foreshadow the humerus, radius and ulna of the higher animals

Emergence of Early Land Vertebrates—Amphibians

As has been already observed, it was in the fast running freshwater streams rather than in the ocean depths that the evolution of animal life received impetus Possibly with the development of lungs, greater assimilation of oxygen took place which accelerated the evolutionary process Apart from lungs, the development of limbs is also an important achievement of animal life, which enabled the animals to conquer land

Lung-fishes, with primitive paired limbs and lungs, probably developed into the early amphibians In *Elpistostege*, discovered from the Devonian of Canada, the skull is intermediate in structure between the crossopterygian fishes and the amphibians Similarly in *Eogyrinus*, a fish-like amphibian discovered from lower Carboniferous, there are rudimentary limbs which are intermediate between the fins of fishes and the limbs of amphibians, and its skull also shows fish-like characters in the form of spaces in the palate

In late Devonian we see the first signs of land vertebrates, in the form of fossilized amphibian foot prints The most ancient foot print, *Thinopus antiquus*, has been discovered from the upper Devonian of Pennsylvania in USA It reveals two completely formed fingers, with the cleft between them extending deep into the sole of the foot,

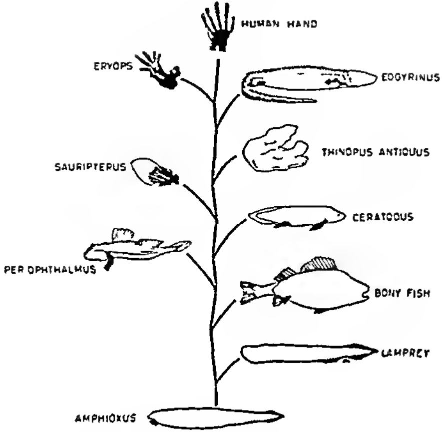


FIG. 31 EVOLUTION OF FORELIMBS CULMINATING IN THE HUMAN HAND

and the bud-like rudiments of the third and fourth fingers. It seems that the terrestrial foot began as a two-toed organ, on the outer side of which the remaining three toes arose in orderly succession till the typical number five was acquired The development of the Salamander's foot shows a similar type of budding as in *Thinopus* track, and corroborates in a striking manner that the ancestral foot began as a two-toed organ. This was the precursor of the five-fingered human hand. Fig 31 shows the probable evolution of forelimbs culminating in the human hand Thus, we see that life made great strides in the Devonian Period. Not only do we see the origin of a land flora from marine or freshwater plants, we also see the emergence of land animals from fish-like creatures.

CHAPTER NINE

THE CARBONIFEROUS PERIOD

(The Coal Age)

The Age of Amphibians and Lycopods

The Carboniferous Period, which had a span of about 80 million years and ended about 205 million years ago, is sub-divided into the lower, the middle and the upper As the name implies, it was adopted about one hundred years ago for the system of rocks which were supposed to include world-wide coal beds In fact it is the later part of the period that contains the world's largest coal deposits Thick deposits of coal also occur in the succeeding period, the Permian, which was originally also included within the Carboniferous but later separated from it The coal deposits of India are largely Permian in age

In India, the lower and the middle Carboniferous constitute a part of the Dark Age which commenced with the Cambrian, the rocks from the Cambrian up to the middle Carboniferous are wanting in most of India, except in the North-West Himalayas, Kashmir, Spiti, Garhwal Himalayas and Tibet Pl 30 shows rock succession in Spiti

In the Spiti area there are over 600 m thick lower Carboniferous rocks, the Lipak Series, made up of hard and dark-coloured limestone with white and grey quartzite Overlying the Lipak Series the black shales and quartzites constituting the Po Series, belong to the middle Carboniferous, which is an important datum-line in the geology of India A continuous sequence of rocks from Cambrian to Permian occurs in Kashmir and in the Chitral River valley

From the upper Carboniferous to the end of Mesozoic, thick land deposits were laid in peninsular India, the rocks of which are referred to the Gondwana system The upper Carboniferous began with a Glacial Epoch, the remains of which are met with in the Talchirs in Deccan, Orissa, Madhya Pradesh, Rajasthan, Simla, Kashmir, Hazara, and the Salt Range

During this period, which is also called the Coal Measure Period, the lands, where large forests grew, sank, and the sinking process was accompanied by repeated small oscillations of level Forest after forest were submerged and sealed under layers of sand and mud, and then raised again to be covered with another forest, which in its turn was flooded,

destroyed and preserved. Thus, we see seams of coal alternating with bands of sand and clay. Although Devonian coal, Jurassic coal and Eocene coal are known from the arctic lands of Spitsbergen or Bear Island, the major coalfields of the world were laid down in the late Carboniferous and Permian. Well over half of the world's present supplies of good coal were laid down in the Coal Measure Period and giant lycopods, like *Sigillaria* and *Lepidodendron*, provided the raw material.

Palaeogeography

During the Carboniferous, profound changes took place in the relative distribution of land and sea. The waters of the Tethys Sea invaded the northern region of India, Tibet and a great part of China. The Tethys was a great central sea which girdled almost the whole of the earth, separating the continents of the northern hemisphere from those of the southern (Fig 32).

Gondwanaland, the great southern continent. Gondwanaland is the name given to the great southern continent which stretched across the world to the south of the Tethys Sea and consisted of the present day South America, South Africa, Indian peninsula, Australia and Antarctica. Medlicott, Feistmantel and Blanford are the founders of the Gondwana system. It was carefully scrutinized by R. D. Oldham in 1893 and has since been adopted by the Geological Survey of India. The rocks of the Gondwana system

FIG 32. MAP OF THE WORLD AT THE END OF THE CARBONIFEROUS PERIOD The shaded areas were land. Areas with darker shading indicate extensive glaciation (After Arldt)

cover a period of about 150 million years, corresponding in age from the uppermost Palaeozoic to the middle Cretaceous To the north of the Tethys Sea were the Angaraland and the North-Western or North Atlantic Continent

Wegener believes that the continents are not fixed entities of the earth's crust and have floated over a viscous floor, farther and farther apart Suess, the Austrian geologist, described the earth's crust as consisting of two zones The upper zone, the Sial, consists of acidic rocks such as gneiss and granite, containing 60-75 per cent of silica and sedimentary rocks of all ages, forming the outer and lighter shell The lower zone, the Sima, consists of heavier basic rocks such as basalt, with a lower silica content Wegener visualizes the continents as a rocky scum of Sial floating on the denser Sima, which beyond the submerged edges of the continents, forms the floor of the oceans The basaltic Sima probably rests on heavier material, iron or an iron-nickle alloy According to this view, the earth is believed to be solid throughout Wegener assumed that Sial was more or less equally spread over the whole surface of the earth and formed the floor of a universal ocean with an average depth of about 3000 m, which he named as Panthallasa Later the granite crust was crumpled up into a world continent, occupying about half of the earth's surface, which he called Pangaea The world continent or Pangaea was disrupted into three land masses, a giant continent in the south, and two continents in the north, separated by the east-west Tethys Sea (Fig 32) These three blocks were further disrupted into smaller blocks which drifted away due to the earth movements According to this view, the sundering oceans are a measure of the distances to which the disrupted pieces of the former giant continents have floated farther and farther apart over a viscous floor Wegener regards the Atlantic as a great rift in the Sial, which has gradually broadened in the course of ages The other view held is that the present continents are fixed portions of the earth's crust and are remnants of much bigger continents which foundered and large areas sank It is possible that vast land areas may have been lost, but available geological, palaeontological and other evidences lend support to the views of Wegener

Rocks in the peninsular India, which range in age from the upper Carboniferous to the Jurassic, form a connected sequence and are a prominent feature of the geology of South India These rocks were first known from the ancient Gond Kingdom, south of the Narmada, and were hence named as Gondwana System by Suess Similar organic and physical features are seen in rock systems of South Africa, Madagascar, Australia and South America There are unmistakable affinities between the freshwater fishes and other lower vertebrate fauna of India, Madagascar and South Africa The Cretaceous dinosaurs of Madhya Pradesh in central India have many resemblances with those of Madagascar, Patagonia, Brazil and Uruguay Perhaps, the most interesting of the earlier discoveries were

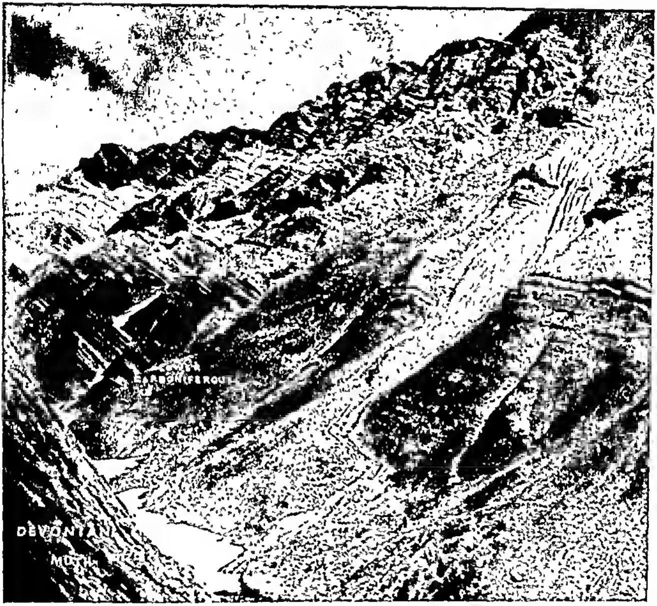
those from South America, of which W.T. Blanford wrote : " . now these discoveries one after another of the exceptional character that have made the Indian, Australian and South African beds famous in the history of geological science, have been completed by the recognition in the South America of that remarkable and characteristic flora which first drew attention to the whole question It is curious how the typical forms of the lower and the upper Gondwanas have been gradually traced in India, Australia and South Africa, how in each case a peculiar boulder bed has been found associated with them, and how every one of the same peculiar features has now been met with in South America Not the least remarkable fact, moreover, is the peculiarly Indian facies of the Argentine flora, the association of *Neuropteridium validum* Feist., *Gangamopteris cyclopteroides* Feist., and *Noeggerathiopsis hislopi* Feist., being characteristic of the Karharbari beds "

Hettner described the coal measures of southern Brazil, and obtained from them fossil plants belonging to the Glossopteris flora Zeiller on examination found these to comprise *Gangamopteris cyclopteroides* associated with *Lepidophloios laricinus* and a *Lepidodendron* Kurtz found a *Lepidodendron* associated with the Glossopteris flora in Argentina

Besides considerable floral and faunal evidences, the physical configuration of the land, which formed the Gondwanaland, lends weighty support to Wegener's hypothesis Peninsular India, Madagascar, South Africa, and South America fit into each other like pieces of a jigsaw puzzle

The intensity of the crustal movements, which gave birth to the Appalachian mountains in the eastern North America, and other earth movements which took place in the Carboniferous Period are believed to have been responsible for the subsidence of large blocks of land in peninsular India and other parts of Gondwanaland. In these sunken troughs, which lie mainly in the Damodar, Son, Narmada, Mahanadi and Godavari valleys, the rivers of the Gondwana land poured their detritus including forest trees These loaded troughs were well preserved among the Archaean crystalline rocks, and it is from the coal seams enclosed in the Gondwana rocks that almost all the coal of India is derived In these troughs, coal was not only made and preserved, but also saved from crushing and folding which would have otherwise destroyed its commercial value by making its extraction difficult and costly The Gondwana deposits are river deposits, as is proved from the nature of the detritus, presence of terrestrial plants, crustaceans, insects, fishes, amphibians and reptiles, as well as from the total absence of marine animals like corals, crinoids, etc.

Gondwana Ice Age. From the presence of boulder beds, striated floor and undecomposed felspar, a Glacial Epoch in the upper Carboniferous of Gondwanaland is well established These boulder beds occur not only in peninsular India, but also in Rajasthan, Salt Range Hazara and Simla Outside India, they occur in Australia and South Africa The lowest beds of the lower Gondwana are known as Talchir Series, after a former



Courtesy GSI, Calcutta

ROCK SUCCESSION IN SPITI, NORTH-WEST HIMALAYAS — LOWER CARBONIFEROUS TO TRIASSIC

RESTORATION OF A SWAMP FOREST OF THE CARBONIFEROUS PERIOD, INCLU

Courtesy Chicago Natural History Museum

GIANT SEED FERNS HORSETAILS AND CLUB MOSSES, AND A PRIMITIVE INSECT

State in Orissa Talchir Series is divided into two stages, of which the lower is recorded from the Rajmahal hills to the Godavari and from Raniganj to Nagpur and consists of green laminated shales and soft fine sandstone The presence of undecomposed felspar grains in the sandstones and striated blocks of rock up to 30 tonnes in weight embedded in a matrix of fine silt indicates that the boulders and rocks were transported in floating blocks of ice, and were dropped in Talchir troughs According to Wadia the Aravallis and the Vindhyans were the chief gathering grounds for the snow fields, and from these the glaciers radiated in all directions

However, in the succeeding strata, the Damuda (Permian), we find thick coal seams, which indicate a luxuriant vegetation and a warmer climate This is followed by another cold cycle in the Panchet Series (Triassic) The Panchet Epoch is succeeded by the middle Gondwana thick red sandstones indicating and desert conditions The comparatively cold climate of Gondwanaland is partly accounted for by the presence of a cold sea with floating icebergs to the south protruding like a wedge between the Gondwanaland and the Antarctic Continent

Warm climate in Angaraland and North-Western Continent. The two large continents in the north of the Tethys Sea were Angaraland and North-Western Continent, the latter comprising North America, Greenland and Norway Between Gondwanaland and the two northern continents there were some groups of islands The rocks of Angaraland, a name derived from the river Angara in Siberia, range from the Carboniferous to the Tertiary, and are characterized by the Kusnetzk flora Significant feature of the Angaraland vegetation is the admixture of Gondwanaland forms and plants characteristic of early Mesozoic floras

A good bit of the western and middle parts of North American–European continent was under the sea In the Permian, the Appalachian troughs ended, and the rocks were folded and faulted into the Appalachian mountains The continent was possibly washed by the warm sea currents

The Carboniferous forests of the northern continents indicate a warmer climate These forests were possibly shrouded in mist, and an atmosphere rich in carbon dioxide Evidences in favour of a tropical or sub-tropical climate are the occurrence of ferns belonging to Marattiaceae, a family now mainly tropical in distribution, the presence of cones on the older parts of the stem rather than on the slender shoots of rare trees like *Sigillaria*, thus exhibiting cauliflory as in tropical trees, and the absence of annual growth rings in the secondary wood of many Carboniferous trees

A Carboniferous landscape in the northern continents (Pl 31) resembled the present day tropical forests in many features There were swamps and marshes and luxuriant vegetation It is thus that Seward describes the Carboniferous landscape in the

northern continents: "Through the wide and melancholy waste of putrid marshes meandered sluggish streams carrying natural rafts of wood and tangled masses of vegetable debris: lakes and lagoons were conspicuous features and there is evidence that at intervals the low-lying ground was invaded by the sea. Almost without exception each seam of coal in North America and Europe rests on a bed of clay, known as the underclay, penetrated by the spreading and forked 'roots' (*Stigmaria*) of *Lepidodendron* and *Sigillaria*. The underclay is the surface-soil of the forests which in the course of ages became seams of coal."

PLANT LIFE

Plant life during the Carboniferous was thus profuse and varied and comprised several groups, viz. lycopods, arthrophytes, ferns, seed-ferns, and gymnosperms. Animal life was equally rich during the period and besides the various groups of invertebrates and fishes in the seas and arthropods on the land, primitive amphibians had become conspicuous. Fig. 33 and 34 give the palaeoscapes of the Gondwanaland and the

FIG. 33 A PALAEOSCAPE OF GONDWANALAND SHOWING PLANT AND ANIMAL LIFE. The predominant trees were *Lepidodendron* and *Cordaites* with an undergrowth of *Gangamopteris* and *Glossopteris*

FIG 34 A PALAEOSCAPE OF NORTH WESTERN CONTINENT SHOWING PLANT AND ANIMAL LIFE IN THE CARBONIFEROUS PERIOD

North-Western Continent respectively, showing both plants and animals in the Carboniferous Period

Lycopods

From the pre-Carboniferous lycopods several lines of development evolved which made this group one of the dominant elements in the vast, low-lying upper Carboniferous swamps of North America and Europe Carboniferous lycopods were mostly arborescent and characterized by unique aspects of morphology and growth Besides the arborescent forms, certain herbaceous lycopods very much resembling the modern *Selaginella*, also existed

The arborescent lycopods attained a height of 30–34 m and a diameter of about 1 m The stem was covered with scars or cushions of various shapes in *Lepidodendron* and *Sigillaria* They were all dichotomously branched, even the root system (*Stigmaria*) was

characterized by dichotomy. The rootlets were, however, borne spirally on the ultimate branchlets. The section of the stem showed a large pith, enclosed by the primary wood, surrounded by a band of secondary wood. Cortex was massive, with an extensive development of periderm or cork outside it. In some species the periderm was of a complex structure and was made up of radially aligned fibrous cells arranged regularly and imparting a storied structure. Periderm made a considerable part of the stem and perhaps served as the supporting tissue.

The leaves (*Lepidophylloides*) were grass-like, 3 to 4 mm wide and about 30 cm long, but the length was variable. They were borne towards the terminal portions of the ultimate branchlets and on falling left a characteristic scar. The midrib was made up of an elongate group of tracheids, surrounded by the phloem and the transfusion tissue. There was abundant hypodermal tissue in the lamina.

The spore-bearing cones were built on the same plan as that of modern lycopods but were much larger. The cones of *Lepidostrobus diversus* had microsporangia in the distal part and megasporangia in the basal part, and both mixed up in the middle. In the shape of the sporangia, their mode of attachment and the presence of ligule, they resembled the modern lycopods. An evolutionary sequence noted in the heterosporous lycopods in the Carboniferous reveals a reduction in the number of megaspores per sporangium, an increase in the size of megaspores and finally enclosure of the megasporangium by the sporophyll to form a seed. The last stage is seen in *Lepidocarpon*, in which the seeds are attached to the cone axis. *Lepidocarpon* seed is an integumented megasporangium and represents the peak of evolution attained by the ancient lycopods. But its integument is certainly not homologous with that of the seed plants.

Sigillarias and Lepidodendrons seem to have evolved from forms like the upper Devonian *Archaeosigillaria primaeva*, which combined features of both.

Arthrophytes (Articulates)

The arboreal vegetation of the Carboniferous included some plants of diverse nature characterized by the articulate form of stems bearing whorled leaves with reproductive organs of unique construction. They had obviously evolved from the Devonian articulates. The *Calamites* amongst them attained a height of 15 m. or more. The stem had large pith and strongly developed secondary wood which was composed of tracheids and wood rays. Xylem was made up of wood sectors, radiating out from the protoxylary canals with large intrafascicular rays lying between them, as in *Arthropitys*. In *Calamodendron*, bands of vertically aligned cells flanked the wood sectors. In contrast to the stems, the roots lacked the jointed organization and had a solid pith but no protoxylary canals.

The foliage was borne in whorls, each having 4 to 40 leaves, either turned upwards

(*Asterophyllites*) or borne at right angles to the stem The leaves were uninerved and lanceolate, but occasionally ovate to spathulate Each leaf had a single median vascular bundle with radially aligned mesophyll cells and conspicuous air chambers

The cones were small and borne singly at the nodes or arranged in terminal groups or infructescences, but some were borne on specialized branches The bracts and the sporophylls were borne in equidistant and alternating verticils, with about 12 bracts in each whorl fused to form a disc at the base with the upturned distal ends separate The fertile appendages were about six in a whorl, each consisting of a sporangiophore terminating in a peltate or cruciate head bearing four sporangia That was the construction of *Calamostachys binneyana* *C casheana* was heterosporous The whorls in *C americana*, another heterosporous species, had 40–45 bracts Some sporangia in this species had megaspores at one end and microspores at the other In *Palaeostachya*, the sporangiophores were borne at an angle of 45° to the axis *Cingularia typica* had strap-shaped sporangiophores with two sporangia borne on the underside, whereas a single pendant sporangium is known in *Stachannularia* Cones in *Kallostachys scotti* were without bracts

The herbaceous articulates were represented by the Sphenophyllales The *Sphenophyllum* stems were characterized by a triangular primary stele occupying the centre Secondary wood was formed in the older stems The wedge-shaped leaves were arranged in whorls of six, eight or nine, distally rounded or divided

There is an array of fossil cones belonging to Sphenophyllales In *Bowmanites*, the spore-bearing organs were arranged in distinct cones made up of whorls of bracts fused to form a disc The sporangiophores were borne above this disc In *B dawsonii*, the bracts fused to form a funnel-shaped structure, the upper side of which bore several sporangiophores, each with a single anatropous sporangium *Litostrobus iowensis* had 12 basally fused bracts at each node with 6 sporangia, each borne erect on a stout stalk

Of all the articulate cones that of *Cheirostrobus pettycurensis* from the lower Carboniferous deposits of Pettycur, Scotland, is perhaps the most complicated (Fig 35) About 3 5 cm in diameter, it consisted of whorls of appendages, the compound sporophylls A whorl had 12 such units, each divided into a lower and an upper segment The lower segment divided horizontally into three stalks (bracts) which were lanunate and keeled towards their distal ends with the ascending limb divided into two The upper segment divided horizontally into three slender peltate sporangia

Progressive simplicity in the evolution of sphenophyll cones has been suggested by Mamay The most complex of all, *Cheirostrobus pettycurensis*, comes from the lower Carboniferous, the less complex, *Bowmanites*, is from the English Lower Coal Measures, whereas the simplest amongst them, *Litostrobus*, is from the Des Moines Series This wide stratigraphical separation of complex to simple cones is interpreted by Mamay as a

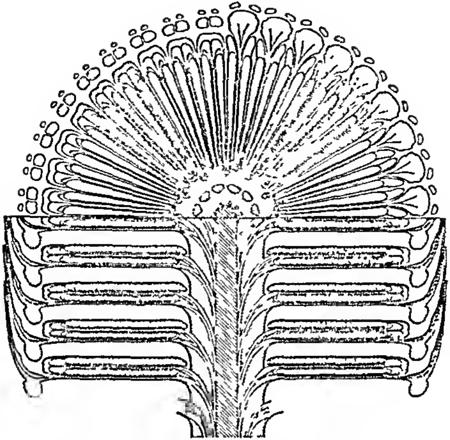


FIG 35. *Cheirostrobus pettycurensis* Cross and vertical sections of the complex cone from the lower Carboniferous of Scotland (After Scott)

progressive reduction. Accordingly, *Litostrobus*, the simplest amongst them, is regarded as a highly advanced rather than a primitive fructification. Although acceptable as a working hypothesis, the problem remains as to how the older complex forms had originated and how they had reached that state. Their rapid decline at the close of the Palaeozoic is probably due to a slow rate of evolution in these highly complex forms.

Ferns

The early ferns, the coenopterids, were characterized by protostelic stems with the fronds three-dimensional in their branching pattern, but usually without lamina. Sporangia were borne terminally. In their size, complexity of their fronds and stem anatomy, they were similar in organization as the protopterids, a Devonian group of plants. Some of them were perhaps reduced forms rather than being truly primitive.

In these primitive ferns, the stem and leaf were not clearly differentiated A coenopterid consisted of a dorsiventral trailing stem and an upright branch system Some of them grew as epiphytes, such as *Botryopteris trisecta* and *Tubicaulis scandens* A conspicuous lacunar middle cortex in the stems and petioles of *Tubicaulis stewartii* suggests that it had an aquatic or semi-aquatic habitat In *Anachoropteris clavata*, petioles functioned as stolons *Stauropteris burntislandica* was heterosporous The megaspores were produced in ovoid megasporangia with a tapered tip, whereas the microsporangia were spherical and borne terminally.

Some coenopterids, like *Ankyropteris glabra*, bore scale-like appendages, the aphlebiae The nodal anatomy of *Ankyropteris* has provided clues to the origin of axillary branching—one of the most characteristic features of modern conifers and angiosperms

Several kinds of fern foliage are known from the Carboniferous Since some of them bore seeds, it is not possible to say if those without the seeds belonged to the seed-ferns or true ferns.

Amongst the true ferns, Marattiaceae were one of the dominant elements. These were graceful tree-ferns with an unbranched trunk and crown of large pecopterid fronds, bearing fused sporangia (synangia). Each synangium included five to nine sporangia The synangia were enclosed in synangial envelopes. In some, synangia were arranged in two rows, one along either side of the midrib of the pinnule.

Some *Pecopteris*-type of leaves bore erect sporangia with apical annulus (*Senftenbergia*) as in the modern Schizaeaceae A clue to the origin of the unique sporangium in this family is provided by some Carboniferous Senftenbergias annulus is regular and two to three cells deep in *S plumosa*, less regular and two to three cells deep in *S. ophiodermatica*, whereas in *S sturi*, the annulus cells are less clearly distinguished from the others and form an irregular patch around one side of the sporangium In the modern Schizaeaceae the annulus is made up of a single row of cells

Evidence of the occurrence of Gleicheniaceae is found in *Oligocarpia* It is a pinnate *Sphenopteris*-type of frond bearing rosette-like sori, each having four to five sporangia The sporangia were attached to a low dome-shaped receptacle and arranged in a single ring Each sporangium had a distinct gleichenoid-type of annulus

There were certain other ferns which bore sporangia, with or without annulus, marginally, at the tip of each lobe of lamina or of a vein (*Acrangiophyllum pendulatum*, *Boweria schlatzlarensis*), but in *Renaultia gracilis* they were borne on the underside of the pinnule, close to the margin

Amongst the Carboniferous ferns there also existed a strange type of group, the Noeggerathiales It had cycad-like foliage and heterosporous cones The elongate cones bore two rows of semicircular scales, each with a fringed margin, bearing numerous

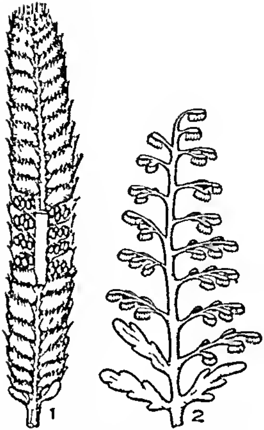


Fig 36 1 Restoration of *Noeggerathiostrobus bohemicus* (After Halle) 2, *Crossotheca* sp Restoration based on a specimen from the upper Carboniferous of Illinois (After Andrews)

sporangia on its upper surface Fig 36 1 shows the restoration of *Noeggerathiostrobus bohemicus* The Noeggerathiales, variously referred to ferns and cycads were perhaps an isolated group of ferns possessing the characters of both ferns and cycads

Seed-ferns

The seed-ferns or the Pteridosperms appeared first in the lower Carboniferous but became abundant during the upper Carboniferous and Permian They possessed fern-like foliage and bore seeds The leaves were either pinnate (*Sphenopteris*-type, *Alethopteris*-type and *Neuropteris*-type) or spathulate, ovate or linear-lanceolate (*Glossopteris*-type and *Gangamopteris*-type) The seeds were either borne singly or in compact cones. The individual seeds were always enclosed in a cupule These were of an advanced structure, having a stout integument, a nucellus and a pollen chamber, with the nucellus and integument either closely knit as in Lyginopteridaceae or separate except at the base as in Medullosaceae

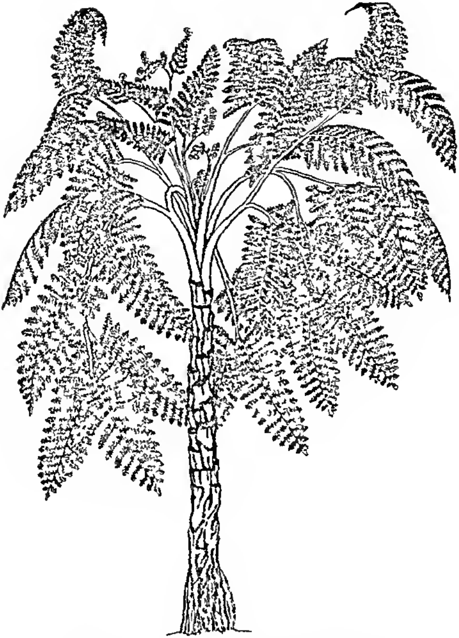


FIG. 37 RESTORATION OF *Medullosa* sp (After Stewart & Delevoryas)

The stem had strongly developed secondary wood, which in *Medullosa* (Fig 37) was made up of separate proliferating steles, some having both the excentric and concentric development of xylem.

The male organs also presented a variety of morphological features The fertile branch system in *Crossotheca* consisted of a terminated part of a *Sphenopteris*-type frond with

ultimate branchlets turned into flattened laminae, each bearing a peripheral row of elongate, pendant sporangia (Fig. 36 2). *Dolerotheca* was a bell-shaped fructification consisting of several hundred tubular sporangia embedded in a cellular ground work. In *Whittleseya* (Fig 38 3), the long tubular concrescent sporangia were arranged in a single ring forming the wall of a campanulate, shovel-shaped structure. Similarly there were other synangial types too.

Some highly evolved devices, especially in the development of pollen trapping mechanism, are seen in the elongate distal lobes of the integument in lower Carboniferous *Calathospermum* (Fig 38 1), and in the elongate, slender, hairy processes extending from the distal end of the integument in the upper Carboniferous *Gnetopsis elliptica*, which were perhaps better specialized for the purpose (Fig. 38.2).

Since true ferns have not been found below the upper Carboniferous, such highly evolved forms as the lower Carboniferous *Calathospermum*, suggest that the seed-ferns have not evolved from the true ferns, but very likely both have originated independently.

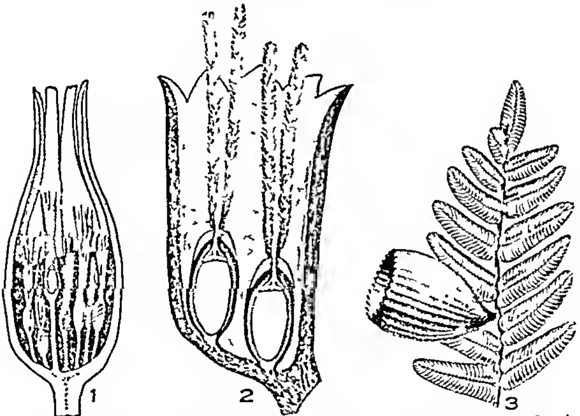


FIG. 38 1. *Calathospermum scoticum* Longitudinal section through a cupule with some of the enclosed seeds. 2. *Gnetopsis elliptica* A cupule from the upper Carboniferous of France with two seeds. 3 *Neuropteris* foliage bearing a *Whittleseya media* synangium A restoration based on specimens from a coalfield in Limburg Holland (1, after Walton, 2, after Renault & Zeiller, 3 after Stewart & Delevoryas)

Cordaites

Cordaitales, chiefly represented by the genus *Cordaites,* along with conifers were the most imposing elements of Carboniferous forests These were trees of monopodial habit, about 30 m tall, with the branches clothed with spirally arranged strap-shaped leaves about a metre in length (Fig 39) The leaves were tough and leathery in texture and in anatomical features very much like the leaves of modern cycads The structure of the wood in *Poroxylon* resembled that of the stem of *Lyginopteris*, a Pteridosperm In the genus *Cordaites,* the primary wood was entirely centripetal and the secondary wood was very much like that of modern Araucarias

The pollen and seed-bearing organs in *Cordaites* were produced on dwarf shoots, each arising in the axil of a bract, longer than the shoot (Fig 39) A dwarf shoot consisted of 25–40 closely imbricated scales with the distal ones fertile and more slender Male fertile scales or appendages bore six long sporangia fused below Female

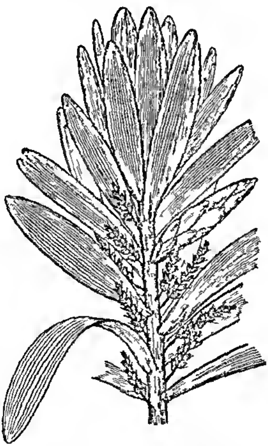


Fig 39 Restoration of a branch of *Cordaites laevis* with inflorescences in the axils of the leaves (After Grand Eury)

inflorescences, built on the same plan as the male, were longer, bearing two rows of dwarf shoots, each in the axil of a bract Apical fertile shoots forked several times and bore two or more recurved terminal sporangia In *Cordaianthus zeilleri*, a geologically younger species, each dwarf shoot bore not more than four unbranched fertile appendages, and occasionally only one, bearing a single terminal ovule The fertile appendages were short and the ovule or ovules were concealed among the sterile appendages Several isolated, bilateral and symmetrical seeds with wings, found in the Carboniferous, probably belonged to the *Cordaites*

Conifers

Besides the *Cordaites*, there were trees in the Carboniferous forests which bore short stout and stiff leaves, either closely appressed to the stem, e g *Lebachia*, or extending out at about 90° to the axis, e g *Ernestiodendron* In their general habit these trees were probably similar to modern *Araucaria excelsa* In contrast to the lax inflorescences of the Cordaites, they had their seed organs aggregated into distinct cones In *Lebachia*, the cones were 6–7 cm long and made up of spirally arranged, closely imbricated bracts forked at the tips Each bract bore a dwarf shoot in its axil The dwarf shoot bore several imbricated scales with one fertile, bearing a terminal ovule *Ernestiodendron* had smaller cones, built on the same plan as that of *Lebachia*, but all the scales in the dwarf shoot were fertile Some species had erect ovules, whereas in others these were inverted

Pre-Ginkgophyte

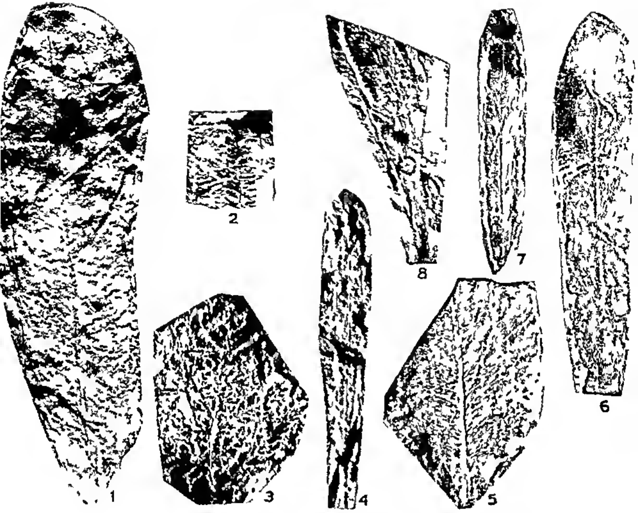
In the upper Carboniferous there was yet another interesting plant, called *Dichophyllum moorei*, known from eastern Kansas Without any demarcation into stems and leaves, the main axis in this plant was divided more or less dichotomously, and each branch ultimately subdivided into linear, slender, terminal branches Associated with this, there were seeds with two horn-like projections at the micropylar end. The presence of a distinct cuticle precludes the possibility of its being a fern It might have been a "pre-ginkgophyte"

Plates 32 and 33 give some of the Permo-Carboniferous plant fossils from India

Advances in Plant Life

The panoramic view of the Carboniferous flora given above, reveals that not only the plant life during this period was profuse, but also showed considerable morphological advancement, both in vegetative and reproductive organs

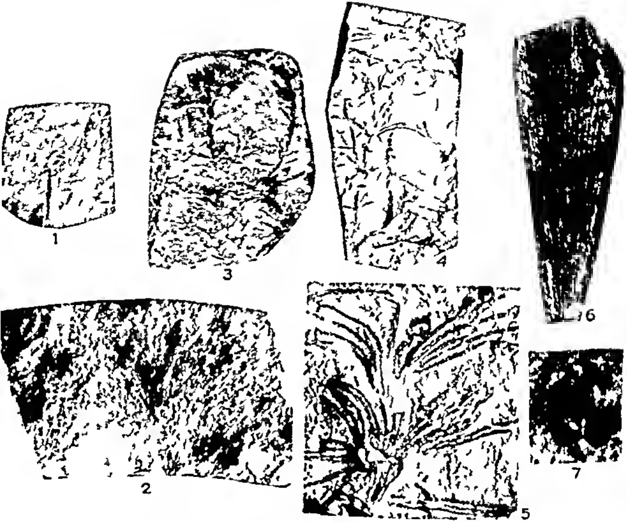
From the viewpoint of evolution, the diverse Carboniferous plant life shows certain common trends in development, some of which are indeed landmarks in the evolution



Courtesy Birbal Sahni Institute of Palaeobotany Lucknow

SOME PERMO-CARBONIFEROUS PLANT FOSSILS FROM INDIA

1 *Glossopteris indica* Schimper 2 *Pecopteris phegopteroides* Feist 3 *Sphenopteris hughesi* (Feist) Zeiller 4 *Glossopteris angustifolia* Brongniart 5, *G browniana* Brongniart 6 *G intermedia* Feist ex Maheshwari 7 *G formosa* Feist 8, *Cistella indica* Maheshwari a glossopterid fructification



Courtesy Birbal Sahni Institute of Palaeobotany, Lucknow

SOME PERMO-CARBONIFEROUS PLANT FOSSILS FROM INDIA

1 *Gangamopteris cyclopteroides* Feistm. 2 *Gangamopteris* sp. venation shown enlarged 3 *Buriadia heterophylla* Seward & Sahni 4 *Phyllotheca indica* Bunbury 5 A part of 4 shown enlarged 6 *Noeggerathiopsis hislopi* (Bunb.) Feistm. 7 *Samaropsis* sp.

of plants over that of the preceding Devonian Period. Simple dichotomy of the vegetative and reproductive organs as witnessed in the Devonian plant life underwent several changes to produce complex forms as seen in the Carboniferous Following Zimmermann's Telome theory, the evolution of most of these complex forms becomes easily understandable In a large measure, Zimmermann's view coordinates the earlier morphological ideas expressed by Bower, Potonie, Lignier and Tansley that the stems and leaves of the vascular plants are of the same origin, and these had been differentiated from a primitive axis and specialized for different functions These views held that isotomic dichotomy was the oldest and most primitive and gradually with the development of unequal growth of the branches (anisotomy) a process of overtopping took place which led to sympodial and monopodial branching The leaf was believed to be a weak overtopped branch of an axial system with finite growth in contrast to the interminable apical growth of the main axis or the other branches The structure of Devonian and Silurian Psilophytales supports the ideas expressed above, since the plant body in them is simply or complexly branched axis, and the fundamental organs are merely specialized parts of this system

Zimmermann considers the dichotomous branching as most primitive, and the land plants to have originated from the dichotomously branching thallus of the marine algae According to him the earliest vascular plants were composed of undifferentiated uniform organs, the 'telomes', and they were the ultimate unnerved segments of a dichotomizing branch system Similar segments between the subsequent points of forking he calls as 'mesomes' Based on internal structure and functions, he differentiates the vegetative telomes (phylloids) from the fertile telomes (sporangia) He believes that the early simple vascular plants underwent certain organogenetic processes during the subsequent geological periods and gave rise to morphologically complex forms

He is of the opinion that the differentiation of the sporophyte into three main directions has ultimately resulted in the evolution of seed plants Lycopods for instance have small, spirally disposed leaves, with sporangia placed in the leaf axils and the axis is actinostelic In articulates, the leaves are small and whorled, the sporangia are borne on the peltate sporophylls and the axis is eustelic Ferns have large leaves primarily arranged spirally, with sporangia borne on the pinnate leaves and the axis is polystelic. In the seed plants the axis is polystelic or eustelic.

The organogenetic processes which have resulted in so much diversity are overtopping planation, fusion, reduction, recurvation and longitudinal differentiation

Overtopping of a uniform truss of telomes and mesomes leads to its differentiation into an axis and the lateral organs the leaves, which are later differentiated into rachis and leaflets Planation brings about a change in the symmetry of an organ The process of fusion

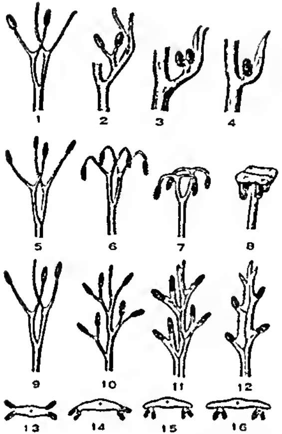


FIG. 40. STAGES ILLUSTRATING THE EVOLUTIONARY STEPS IN THE DEVELOPMENT OF SPOROPHYLLS IN THE LYCOPODS (1–4), IN THE ARTICULATES (5–8) AND IN THE FERNS (9–16) (After Zimmermann)

connects the telomes and mesomes. Thus webbing leads to the formation of leaves with open dichotomous venation or to pinnately veined leaves when overtopping also takes place. These processes are also believed to have led to the evolution of the complex stelar system from the primitive protostele. Likewise the reduction and recurvation of telomes took place. Aggregation is a special type of reduction.

Reproductive organs also evolved in the same manner. It was through the recurving of the pedicels that the sporangia in articulates became pendulous and pedicels and the mesomes fused to form a peltate structure. It was recurvation that brought the sporangia on the underside of the leaves. Overtopping resulted in the pinnate leaf and the lateral fusion of mesomes gave rise to a pinnately veined sporophyll with marginal sporangia (Fig. 40).

The Telome theory of Zimmermann is, thus, one of the plausible ways of explaining the trends in evolution from simple to complex organization and vice versa.

Some of the other important landmarks in the evolution of plant life in general, which characterized the Carboniferous flora, are discussed below

Thick-walled spores: Conquest of land. The Carboniferous Period was the age of pteridophytes, like lycopods and ferns, varying from delicate herbs to gigantic woody trees The sporophyte in ferns has usually a subterranean stem bearing a number of fronds or leaves On the lower surface of the leaves, are borne groups of sporangia, covered with shield-like coverings, called indusia The sporangium is a sac-like body which opens at a particular spot. Each sporangium contains a number of spores which are shed on moist earth The spores have a thick wall which protects them against desiccation and thus they are able to survive in dry air This is a major advance which enabled amphibious plants like ferns to firmly colonize the land

To understand the vegetation of the past, it is necessary to know the present As living beings go on evolving from simple to complex organisms, there continue to remain some of the simple forms Out of these *Selaginella*, *Lycopodium* and *Equisetum* are the most important (Fig 41) as they provide a glimpse of the vegetation of the Carboniferous Let us examine their life cycles so that we may understand them better

From each successful spore a prothallus or the gametophyte is produced The prothallus of the fern *Aspidium* is heart-shaped and is fixed in the earth with the aid of rhizoids On the ventral surface of the prothallus are borne the female sex organs, the archegonia, and the male organs, the antheridia The archegonia are flask-shaped bodies with a neck and a swollen venter containing an egg cell The antheridia are dome-like structures which produce a number of sperms In ferns, we thus see that there are two independent plants, the asexual one which bears leaves, stem and roots, the so-called fern plant, which produces asexual spores, and the prothallus or the sexual plant, which is a green creeping structure of the size of a human nail, and bears the male and female sex organs The sperm floats about in drops of water, enters the neck of the archegonium and its male nucleus fuses with the egg nucleus The fertilized egg or oospore divides and re-divides, thus producing the embryo The embryo clings to the mother prothallus for some time by its foot and then gives below a root, which pierces the prothallus and probes into the soil, and produces stem and leaves above Plants like the ferns with elaborate prothallus are truly amphibious, as their sexual generation can only grow in moist places Even if the main plant can grow in dry conditions, it is tied by the prothallus to moist places In fact, the existence of an independent prothallus, which is dependent upon water and moisture, is a hindrance to the further conquest of the land

Heterospory and seed habit. In plants like *Selaginella* certain material advances are seen as compared with ferns The most notable advance in *Selaginella* is heterospory

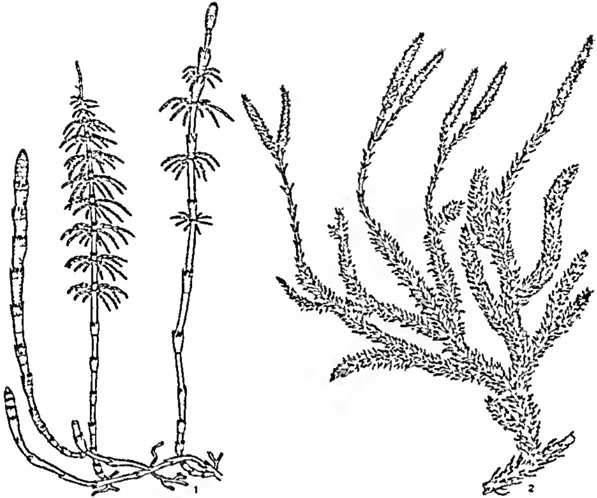


FIG. 41 LIVING FOSSIL PLANTS WHICH HAVE A CLOSE RESEMBLANCE WITH CARBONIFEROUS PLANTS. 1, *Equisetum pratense*. A related species is commonly found on the river banks of India. 2, *Lycopodium clavatum*. It grows in the Western Ghats in South India

In some of the sporangia, usually all the spore mother cells function, and divide and produce numerous microspores. The sporangia bearing the microspores are called microsporangia, and leaves bearing them are called microsporophylls. In some sporangia, extensive abortion of mother cells takes place, and only one mother cell, which produces a tetrad of only four spores, is produced. In some cases, even out of this tetrad only one or two spores mature. The remaining spores provide food material for the surviving spore or spores which are called megaspores, and are borne in sporangia called megasporangia. The microspore germinates and produces the male gametophyte which is a comparatively simple structure. The microspore divides into two cells, a small vegetative cell and a bigger antheridium initial cell. The solitary antheridium, which produces a number of sperms, develops from

the antheridium initial cell The male gametophyte in *Selaginella* is thus reduced to one vegetative cell and one antheridium The female gametophyte develops from the megaspore by repeated divisions A cushion of cells is formed at the apex of the megaspore, while its body below is free from cells and acts as a food reservoir The investing wall of megaspore cracks at the apex, and exposes an expanded mass of tissue in which the female sex organs or archegonia develop By the development of two types of spores, megaspores and microspores, and two kinds of prothalli, a division of labour came into being The female-producing spores are larger in size as compared with male-producing spores, for the female sex organs require a bigger space Thus we see sex being thrown back from the gametes on to the prothalli, and from the prothalli on to the spores from which they take their origin The male gametophytes are brought to the megasporangia by wind or gravity The sperms enter the archegonia and fertilization occurs The embryo feeds on the food material stored at the base of the female prothallus Development of heterospory among pteridophytes like *Selaginella* made the evolution of seed plants possible An approach to seed condition is seen in *Selaginella*, where the megaspores are not shed but are retained within the megasporangium, within which the female gametophyte develops, the egg is fertilized and the embryo or the young sporophyte is formed

Strobilus or Cone In ferns, sporangia are found on the lower side of the leaves, and there is generally no distinction between sporangia-bearing and sterile vegetative leaves In the fern *Osmunda*, the sporangia-bearing portions of leaves are marked out from the purely vegetative parts In *Selaginella*, the sporophylls are clustered together and form a loose strobilus Thus differentiation of sporangia-bearing leaves from vegetative leaves and their clustering into one zone is an important step towards cone and flower-making Loose, cone-like structures are seen in some species of *Lycopodium*, and definite compact cones are seen in species of *Equisetum*

In the Carboniferous Period the plants were perfectly at home on land and had won the shores, the swamps and the lowlands, which were covered with a green carpet of vegetation The swamps and moist places were green with liverworts, mosses, and the prothalli of ferns and other seedless plants Herbaceous lycopods and ferns were abundant, and were of many more varieties than can be imagined even by the dwellers of temperate countries of today Seed-ferns were also very common *Neuropteris* was a common representative of the group, bearing rows of oblong rounded leaflets, and also large tapered seeds in place of some of the leaflets True tree-ferns were represented by *Psaronius* which was characterized by the attachment of fronds in two opposite series

Glossopteris and *Gangamopteris* were other characteristic plants of the Gondwanaland *Gangamopteris* was a pteridosperm and several species of this broad-leaved genus have been recorded from Talchirs (upper Carboniferous) The curious fossil,

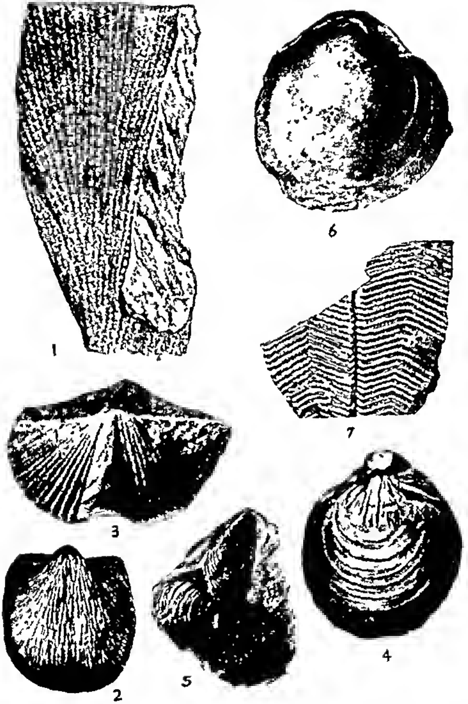
Vertebraria indica, which was regarded as an equisetaceous plant, is now believed to be the rhizome of *Glossopteris* The winged seed *Samaropsis*, and branches of *Dadoxylon* are also associated with *Glossopteris* leaves (Pl. 32 and 33)

It is, however, the clubmosses which were the dominant plants of the Carboniferous Period, and were the lords of the forests The handsome scale-trees, Lepidodendrons, with their pillar-like trunks, embossed with a beautiful scales pattern, raised their heads above all other forest trees These lozenge markings indicate the scars left by fallen leaves Near the top, the Lepidodendrons branched into a fine crown, with the forked trunks and branches covered with small leaves ending in a spore-bearing cone The companions of the Lepidodendrons were the Sigillarias, the seal-trees, so-called from the pattern of leaf-scars on the stem Sigillarias were mostly unbranched and soared upwards into an elongated conical summit encased in a tuft of long pair-like needles, and bore clusters of stalked slender cones

The swamps of the Carboniferous Period were studded with jointed plants, the calamites, distinguished by their transverse nodal lines and frill of leaves round each joint, and branches bearing stalked, long and narrow cones Like the rushes of today, calamites filled the bogs and marshes of the Carboniferous Period. The columnar stumps of calamites were bare below, where branches had been cast off, and the bark was fissured by the continued expansion of the wood within From their creeping subterranean stems, jointed pillar-like stems, resembling magnified horsetad stems of today, arose above, imparting a characteristic appearance to the Carboniferous landscape There were many varieties of calamites differing from one another in the shape or size of leaves, and in the arrangement of slender branches Other members of the arthrophytes were *Schizoneura* and *Phyllotheca* *Phyllotheca* was a comparatively small plant with jointed stem, and cup-like whorls of leafy sheaths cut into short linear segments *Phyllotheca* also occurs in the upper Carboniferous rocks in Asia Minor and in Permian rocks in Siberia The most fantastic trees were the tree horsetails, some of which were as high as 18 m Scrambling over the branches of the calamites, were sphenophylls, the climbing horsetails, bearing whorls of wedge-shaped leaves.

Another significant small tree was *Psygmophyllum* with divided *Ginkgo*-like leaves. *Cordaites*, the predecessors of our conifers were very characteristic of the Carboniferous forests. They were tall and slender trees, some over 30 m high, with beautiful leafy crowns Their leaves were long and strap-shaped, resembling some of the larger-leaved species of the tropical conifer, *Agathis*

The colonization of land by plants started in the Devonian Period, when the leafless sporophytes of Psilophytales escaped from the parasitic existence on the prothallus With



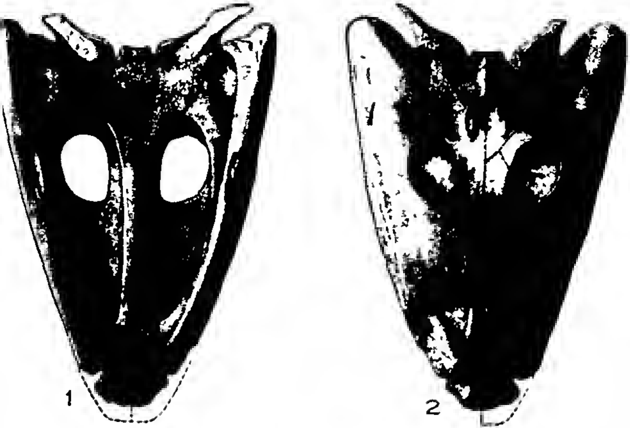
Courtesy GSI, Calcutta

SOME CARBONIFEROUS ANIMAL FOSSILS FROM INDIA

1, *Protoretepora ampla* Lonsdale, 2, *Productus spitiensis* Dien, 3, *Syringothyris cuspidata* Mart , 4, *Dielasma lidarense* Dien, 5, *Modiola lidarensis* Dien, 6, *Eurydesma hobartense* (Johnston) var *rotundata* Reed, 7, *Conularia punjabica* Reed (1, Bryozoa, 2-4, Brachiopoda, 5 & 6, Lamellibranchiata, 7, Pteropoda)

Courtesy American Museum of Natural History, New York

RESTORATION OF DIPLOVERTEBRON, A GENERALIZED AMPHIBIAN FROM UPPER CARBONIFEROUS OF PENNSYLVANIA



Courtesy GSI, Calcutta

SKULL OF GONDWANOSAURUS BIJORIENSIS, BIJORI LABYRINTHODONT, RECOVERED FROM CHHINDWARA, MADHYA PRADESH

the aid of thick-walled spores, they could survive and spread in a subaerial environment Soon after, leafy structures along with vascular tissue were evolved With the manufacture and storage of larger quantities of food material, great possibilities for further advance opened out The adoption of heterospory and seed habit in plants like the lycopods such as *Lepidodendron*, seed-ferns, the pteridosperms and the spermatophytes like *Cordaites* afforded greater protection to embryos of these plants, and opportunities for dispersal over wider areas were opened out. Thus, plants which were formerly restricted to the swamps or the sea shores, also invaded the hinterland and colonized larger areas of the earth, and made them fit for the existence of higher types of animals too

ANIMAL LIFE

Invertebrates

Among the lower forms of animal life, Brachiopoda retained their leadership in the Carboniferous Period, and a large number of genera and species have been recorded from Kashmir and Spiti Another group of invertebrates, the stalked crinoids, the so-called sea-lilies, also became abundant They must have colonized large areas of the sea bottom, and their waving heads must have presented a remarkable sight, resembling a field of wheat at harvest time Insects of many varieties have also been recorded There were cockroaches, several centimetres long, and also dragon-flies with a wing spread of nearly 70 cm But insects of higher types like bees and butterflies had not yet appeared and they evolved much later with the flowering plants Some of the Carboniferous animal fossils from India are given in Pl 34

Vertebrates

Sharks, which had appeared as an inconspicuous group of fishes in the Devonian, developed rapidly and many species are known from the early Carboniferous Period Evolution of limbs and lungs was forced on the mud-fishes by the drought which prevailed in the Devonian Period, and by the oxygen starvation in the stagnant pools and lagoons which were choked with vegetation However, it is the amphibians with clumsy bodies and short legs, which were dominant forms in animal life of the Carboniferous Period

Wells and Huxley describe the animal life of this period as follows "Among the land-folk are also a few little ancestral reptiles insignificant in themselves, but rich with promise In and out of the vegetation there run cockroaches in plenty, large and small, with mites and scorpions and centipedes and ancestral spiders and a few land-snails to keep them company. It is a strange world, and a varied world No birds nesting or singing in the trees, no bellowing, roaring, squeaking or howling of mammals, savage or small,

no flowers anywhere, no fruits, no caterpillars to eat the leaves, no bees or butterflies, the forest, without colour of flowers or of autumn leaves (for there is no change of seasons here), is a symphony in brown and green with yellow veils of sporedust sinking into black pools below

On the ground and the swamps crawl and swim the Carboniferous vertebrates Most of them are amphibians, but amphibians that will surprise anyone who thinks of amphibians solely in terms of frogs and salamanders There are also fish-eating creatures with long snouts like alligators There are legless wrigglers and swimmers, some have fantastic flat heads nearly as big as their bodies, others are plump and hideous, with patches of armour plating here and there on their heads and backs Many of these are permanent water-dwellers, having sunk back to their ancestral element after the briefest taste of the land world. But some of them, as T H Huxley put it, pottered with much belly and little leg like Falstaff in his old age, among the coal forests "

Plate 35 gives a restoration of *Diplovertebron*, a generalized amphibian from the upper Carboniferous of Pennsylvansa

Evolution of Limbs. Limbs were the main achievements of amphibians, but a few used them fully Forms, like *Diplocaulus*, with flattened head, a wide-gaping mouth, and a wriggling body about 1 8 m long, used their limbs more as paddles Permo-Carboniferous *Archegosaurus*, with a body about 1 5 m long, and an elongated snout, occasionally used its legs for moving from one part to another Allied to *Archegosaurus* is the Permian *Gondwanosaurus*, a labyrinthodont, known from Bijori in the Narmada valley Pl. 36 shows the skull of *G bijoriensis* The Mangli labyrinthodont, *Brachyops laticeps* Owen is closely related to *Micropholis stowii* Vux from the Beaufort beds. The aberrant genus *Dicynodon* is represented by no less than thirteen species in South Africa, and is not known elsewhere except from the Panchet group and from reported Triassic beds in North America, along with *Ptychosiagum orientale* The bulk of amphibians went on living eating and breeding in water Their gilled tadpole stage kept the amphibians tied to their aquatic environment. However, there were some amphibians who used their legs more often They left their ancestral pools and crawled on earth in search of food. While chasing their food on land, their legs became more powerful, and their skin tougher and harder Such were the stegocephalians, the first precursors of the land vertebrates, and their progeny has inhabited the earth. The stegocephalians were weak-backed crawlers which colonized salt waters Forms, like *Archegosaurus*, had long snouts like crocodiles, and probably fed on fish It was forms like these which were the ancestors of modern amphibians, and also of the first reptiles and were ultimately the ancestors of higher vertebrates

CHAPTER TEN

THE PERMIAN PERIOD

The Age of Pteridosperms and Primitive Reptiles

THE NAME Permian was adopted in 1841 by the British geologist Sir Roderick Murchison after the province of Perm in north-eastern Russia, for the strata intermediate between the Carboniferous and Triassic Systems which are greatly developed in the flanks of the Ural Mountains This period lasted for 25 million years from 205 to 180 million years ago The earth movements which commenced in the Carboniferous Period attained their culmination in the Permian High mountain ranges were formed and there was also volcanism In the northern hemisphere, arms of sea were at times cut off by the warping of the earth's surface giving rise to land-locked seas In arid regions, deposits of potash and salt were formed by the drying up of these seas In moist, warm, or temperate regions, grew dense vegetation from which coal was formed. In fact, the main coal formation period of Gondwanaland is Permian Fig 42 gives a map of India showing the distribution of coal fields A barrier of coal, across Korea Nala in Madhya Pradesh, is shown in Pl 37

Palaeogeography

The Gondwanaland. The Tethys Sea extended its arms in various directions towards the Gondwanaland, viz. in the Salt Range of Pakistan, Kashmir, Spiti, Kumaon, *Nepal, Sikkim and the foothills of the Assam Himalayas, maintaining communication* between the European and the Chinese seas by way of Turkistan, Iran and the Kun Lun throughout most of the Permian Period Gulmarg in Kashmir, where highly tilted *Gangamopteris* beds at an altitude of about 4100 m have been discovered was perhaps the most northernly extension of Gondwanaland. To the east of this region a bay of the sea spread over upper Burma and in the west over the Salt Range or Baluchistan An arm of the Tethys Sea extended from the Persian Gulf to the shallow end of a trough in Umaria coalfield region of southern Rewa through Gujarat and along the Narmada-Tapti valleys On the floor of the Tethys were formed the deep water deposits from the beginning of the Permian to the middle of Eocene Period constituting the great Aryan system of Indian geology. Except for this sea incursion, land conditions prevailed

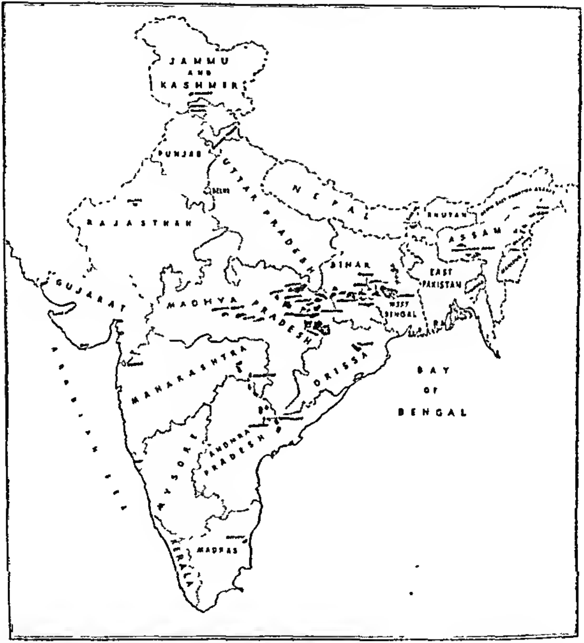
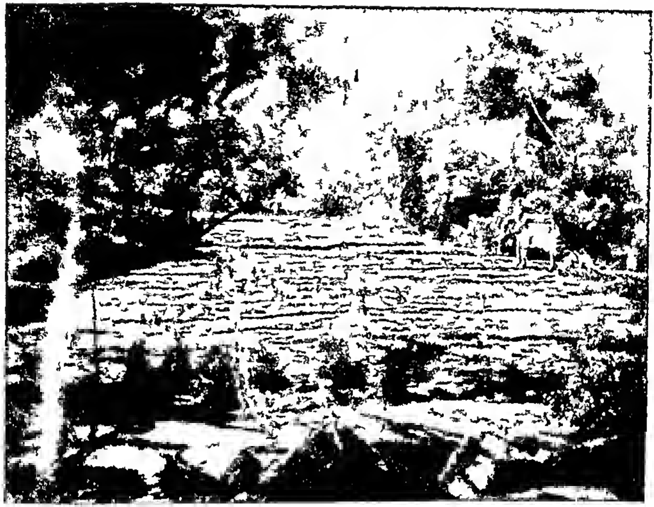


FIG. 42. MAP OF INDIA SHOWING DISTRIBUTION OF COAL FIELDS. The coal fields of Madhya Pradesh, Bihar, West Bengal, Maharashtra, Andhra Pradesh and Orissa are Permian, whereas the coal fields of Jammu and Kashmir, Madras, Rajasthan and Assam are Tertiary



Courtesy GSI Calcutta

BARRIER OF COAL ACROSS KOREA NALA IN MADHYA PRADESH

An elephant is standing on the parting between the two coal seams

in the peninsular India. The ice sheets of the Talchir Epoch, no doubt, eroded away many minor hills and filled up many valleys with debris, the Aravalli range still remained a great mountain forming the main watershed of the north-western Indian angle of Gondwanaland. The Vindhyan ranges and the Eastern Ghats also continued to be highlands.

There were three major river valleys, impressed upon faulted troughs coinciding with the present day valleys of the Damodar–Son in Bihar and West Bengal, the Mahanadi in Orissa and Madhya Pradesh, and the Godavari and Wardha in Maharashtra and Andhra Pradesh. These valleys were bordered by mighty hill ranges and interrupted by extensive swamps which became transformed into temporary lakes in periods of flood. In such lakes and in flood plains was laid down a thick series of lacustrine or fluviatile deposits, with *intercalated plant remains which ultimately formed the coal seams, constituting the fresh-*water Damuda Series, the equivalent of the Permian. The series has been named after the Damodar river which flows through the Bokaro, Jharia and Raniganj coalfields of Bihar and West Bengal. The rocks of the series, besides their major distribution in three linear tracts of the Damodar–Son, Mahanadi and Godavari–Wardha valleys, are found as detached outcrops along the foothills of the eastern Himalayas, in Darjeeling, Sikkim and Bhutan, and in the Aka, Daphla, Miri and Abor hills in Assam. Fig. 43 gives maps of India showing exposures of Permian formations and the geography in this period. Palaeogeographic map of Gondwanaland* is given in Fig. 44.

It is thus that Cyril Fox describes the Indian Gondwanaland in the Damuda Period: "When we endeavour to unravel the geography of the Permian and upper Carboniferous Period, we begin at the earlier date with a continent buried under a vast sheet of

* On what data are these maps of the geological periods based? you will ask. These reconstructions are based on inferences from a variety of facts. If we find a deposit containing fossils of marine animals it is an indication that the particular region was under the sea. A break in a series of marine deposits indicates that for part of the time the region was above the sea. The gradual change from fine clays to coarse sands as we follow them from one region to another indicates the existence of land not far from the region of coarse sands. The discovery of the same marine fauna in two widely separated localities indicates a sea connection between them in the past. On the other hand, the presence of different marine faunas of the same age suggests a land barrier between the two regions. The presence of similar land plants and animals in distant regions points to a land connection between the two regions which may be widely separated now. On the other hand, the presence of different plants and animals in the rock strata of the same age in distant regions points to a barrier which may be a sea channel, a desert, or a range of mountains. The presence of a deposit laid down in fresh water or on land indicates the presence of land. However, it is very seldom that clear evidence of this type is available. This is particularly so in peninsular India where extensive block faulting has occurred, and considerable denudation of the land has taken place. Under such conditions, the presence of fresh water, estuarine or marine formations does not lead us to exact locations of true shore lines and the extensions of the ancient seas. In the present extra-peninsular Indo-Gangetic region considerable folding and faulting has occurred and consequently shortening of the land surface has taken place. Moreover, it is also likely that the continents have drifted. Hence, it is evident that large amount of guess work is involved in palaeogeography and the problem of elucidating the ancient distribution of land and sea is not so simple. Numerous reconstructions of distribution of land and sea in different periods have been published by various authors which naturally differ widely. Arldt has combined them and has produced a number of maps which are based on the largest measure of agreement between the various palaeogeographers and geologists.

continental ice which appears to have moved northward up the Godavari and Mahanadi valleys and eastward down the Son–Damuda valleys In the far north, the ice appears to have entered the sea and drifted on as icebergs and floes to the Salt Range and Hazara and Kashmir in one direction and to the area of the Simla hills in another The retreat of the ice in uppermost Carboniferous times disclosed a sea in the Salt Range and Kashmir areas in which *Eurydesma globosum* lived. These animals are so closely related with species found in strata of the same age in New South Wales that we are obliged to admit a direct sea connection between the two areas The problem is 'Along what line did such a sea-way lie?' The simplest solution for the present is to take the valley of the Ganges as the channel of that connection In lower Permian times came the transgression of the Tethys from the north bringing in a rich productus fauna After considering all possible factors—faulting along with the Son–Narbada valley, etc. I am prepared to accept a possible connection southward from the Central Himalaya into Central India about Umaria as suggested by Fermor"

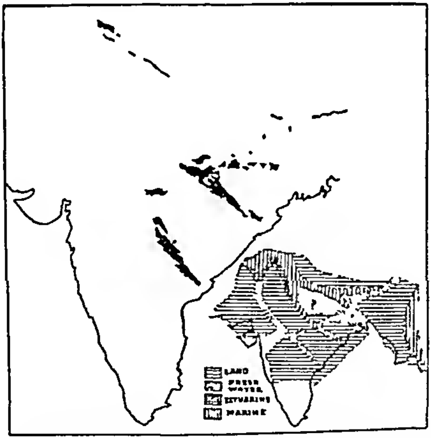


Fig. 43 Map of India showing exposures of the Permian formations The geography of the Indian portion of Gondwanaland in the Permian (Damuda) is shown below (After C.S. Fox)

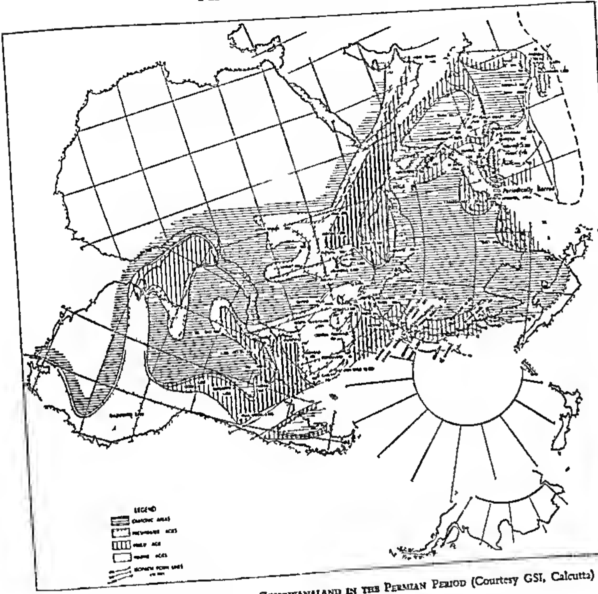


FIG 44 PALAEOGEOGRAPHIC MAP OF GONDWANALAND IN THE PERMIAN PERIOD (Courtesy GSI, Calcutta)

What is the explanation of this Ice Age in peninsular India, which is now entirely tropical? According to Wegener's hypothesis of continental drift, the continent of Gondwanaland was nearer to the South Pole in the Permian Thus its nearness to the South Pole explains the Ice Age. Later on, when the continents drifted apart, peninsular India came to occupy its present position between the Equator and the Tropic of Cancer

The Ice Age which has been described for Indian Gondwanaland, was of particularly wide extension as is evident from boulder clays which have been found in every part of Gondwanaland Mountain ranges made their appearance at this time in Australia, and a

large area of this southern part of Gondwanaland was covered by ice sheets. Similarly, South Africa, and the southern tip of South America were also extensively glaciated.

The North Atlantic Continent. The North Atlantic Continent presented a U-shaped appearance, one arm of the U consisting of the primitive North American continent, the Nearctis, and the other consisting of Greenland and western Europe, including Scandanavia, the North Atlantic proper. Separating the North Atlantic from Angaraland was the Volga Sea which covered European Russia, and was linked with Tethys Sea and Pacific Ocean in the region of central Asia. According to Brooks, a warm current washed the western shores of Angaraland and the eastern shores of North Atlantic, thus inducing a mild climate. It is on the assumption of a warm current that the presence of corals in Volga deposits is explained. Angaraland and North Atlantic had a warmer climate, received comparatively heavier rainfall and supported a luxuriant vegetation.

In the North Atlantic Continent, the Permian was a period of great changes. Over a wide tract of North America and Europe, land extended its boundaries. In the western or central part of North America, the Appalachian Trough ceased to exist and due to the folding of the eastern crust, the Appalachian Mountains were born. In place of wide stretches of open water, there was a land-locked sea, and the dry conditions favoured the deposition of the layers of salt on the floors of the lake basins. By the end of Permian, the whole of North America emerged from the sea, and a period of erosion of the entire continent set in lasting well into the Triassic. There was a change from a humid to a relatively dry climate. The swamps of the Carboniferous, bearing luxuriant forests were transformed into arid land, as is indicated by the accumulation of thick sheets of red sand.

Climate

The retreat of ice towards the close of Carboniferous resulted in gradual warming up of the climate in Gondwanaland during the Permian. The climate must have fluctuated from sub-arctic to cool temperate. The restoration of water from the melting of ice to the sea resulted in the lower Permian transgression of the Tethys Sea from the north and possibly from the central Himalayas into central India as far as Umaria. Several large lakes then existing in the peninsula had eastward outlets to the sea down the Damuda and the Brahmaputra valleys. Soon the climate became warm temperate and humid, when lakes, marshes and swamps abounded with luxuriant vegetation. It was during this time that extensive peat was formed in marshes and swamps, to which an enormous debris of vegetation was also carried by the streams. This peat later turned into coal. During the upper Permian, the climate became dry and arid, which prevented peat formation, although flood plains and shallow lakes did exist.

The Permian transgression of the sea affected other continents also Evidences for the occurrence of arid climate have been obtained from other parts of the world especially Europe and North America in the form of salt, gypsum and potash deposits and red sandstone

There is, however, difference of opinion as to the dating of the commencement of Permian Period from the glacial beds lying below, which according to some specialists belong to the upper Carboniferous In any case, the Permian Period witnessed changes in climate, mountain building and marine transgression In India the late Palaeozoic glaciation is referred to the upper Carboniferous and the best climatic conditions favourable for copious plant growth occurred in the mid-Permian Consequently, we have the best developed coal deposits from this period The same applies to other parts of the vast Gondwanaland, but in other continents the conditions were different so that distinct floral provinces existed

PLANT LIFE

Climate in the early Permian was on the whole unfavourable to plant life From thousands of species in the Carboniferous, it was reduced to only a few hundred in the Permian A general reconstruction of Permian landscape showing plants and animals is given in Fig 45 The lycopods were still represented by stray species of *Sigillaria*, and Equisetales by forms like *Equisetites Calamites* and *Schizoneura* Ginkgoales were represented by *Trichopitys heteromorpha*, *Sphenobaiera*, and *Psygmophyllum*, a tree with leaves resembling those of *Ginkgo* In *Trichopitys* and *Sphenobaiera*, the leaves were much longer and divided dichotomously into long and narrow segments The leaves in *Sphenobaiera* were arranged on short and long shoots Coniferous vegetation included *Lebachia* and *Ernestiodendron* both of which were also present in the Carboniferous, and *Carpentieria*, *Pseudovoltzia* and *Ullmannia* These early conifers show interesting steps towards the evolution of seed-cones of modern conifers Pteridosperms, and many other trees flourished in the North Atlantic Continent from Europe to North America, some even reaching the Atlantic regions At the end of the first half of the Permian Period we see a second transformation The swamps and luxuriant forests of the Carboniferous were transformed into arid wastes with very sparse vegetation The large patches of rich vegetation due to the luxuriance and variety of the cordaites, pteridosperms and the arborescent lycopods, and calamites were reduced to inconspicuous vestiges, possibly due to changes from a humid to a relatively cold and dry climate

Due to the prevalence of a variety of climatic and physiographical conditions, the plant life of the Permian was distributed into distinct floral provinces, for instance, the

FIG. 45 A RECONSTRUCTION OF PERMIAN LANDSCAPE SHOWING PLANTS AND ANIMALS

Gigantopteris flora of the Far East, the Glossopteris flora of Gondwanaland and the Kusnetzk flora of Angaraland

Gigantopteris Flora of the Far East

The Permian vegetation of north China and Korea indicates more or less arid conditions, and shows affinities with the Permo-Carboniferous floras of North America and Europe which flourished in a moist tropical climate Out of 103 species described from China, 20 species are identical with European forms, 14 are North American and 70 are new, but many of these belong to genera which are abundant in the northern floras One of the indigenous plants of north China is *Lobatannularia*, an equisetaceous genus bearing fan-shaped whorled clusters of linear leaves on branches Other members of Equisetales are *Asterophyllites* and *Annularia*, and a solitary species of *Calamites, C sucko wii. Sphenophyllum* is represented by several species Lycopods are represented by species of *Lepidodendron* One of the most striking plants is a pteridosperm called *Gigantopteris,* with fronds about a metre in length, bearing large lateral leaflets with toothed margin It is so widely distributed in the Permian flora of the Far East, that it

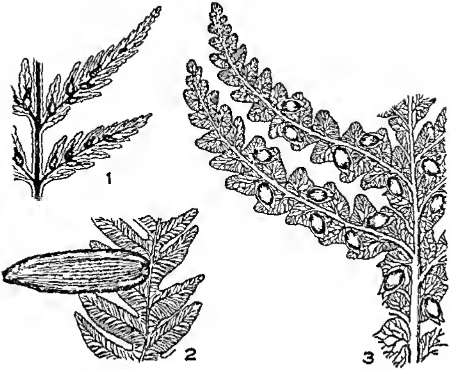


FIG 46 FERTILE (SEED-BEARING) PTERIDOSPERM FOLIAGE FROM THE PERMIAN OF CHINA 1 *Sphenopteris tenuis* 2, *Alethopteris norinii* 3 *Emplectopteris triangularis* (1 & 2 after Halle 3 after Andrews)

has led to the naming of this flora as Gigantopteris flora Fertile leaves of a few pteridosperms from the Permian of China are shown in Fig 46

Glossopteris Flora of Gondwanaland

To meet the new conditions of environment, after the retreat of upper Carboniferous ice and with the progressive amelioration of climate, new types of plants, bushy in growth, harder, and with thicker and rougher leaves, evolved in Gondwanaland. Fossil remains of a pteridosperm, called *Glossopteris*, are very common, and due to the predominance of this plant, the flora of the Gondwanaland is called Glossopteris flora *Glossopteris* had long tongue-shaped leaves, with a midrib and a network of lateral veins, bearing seeds Two-winged pollen grains, *Pityosporites antarcticus*, originally described by Seward from Graham Land, within a few degrees of the South Pole, are now recognized as those of *Glossopteris*, and have been discovered from India, Australia, Africa and Antarctica *Glossopteris* leaves, bearing female reproductive organs, have recently been described from the lower Permian of Vereeniging in the Transvaal by Plumstead. The rounded or ovate, bilaterally symmetrical cupules attached by a pedicel to the midrib of the leaf are believed to be the seed-bearing organs Plumstead believes that the cupules in

these fructifications (*Scutum*) were closed after fertilization, thus showing the possibility of angiosperm relationship

The rhizomes contain bordered tracheids of the gymnospermous type On the other hand the epidermis of *Glossopteris angustifolia* resembles that of angiosperms Based on the structure of the *Glossopteris* fructifications, Plumstead advocates the origin of modern angiosperms from the Glossopteris flora

Another common genus was *Gangamopteris*, also a pteridosperm with larger leaves, and a fully developed midrib *Glossopteris* and *Gangamopteris* were probably shrubby in habit Pl 38 shows these plants in a palaeoscape of Gondwanaland in Permo-Carboniferous Period. *Gondwanidium* was another pteridosperm with long fronds bearing two rows of larger and deeply lobed leaflets A few pteridosperm fronds similar in appearance to those recorded from the northern hemisphere have also been found in India Some Permian plant fossils from Panchet hills in Bihar are shown in Pl. 39 The relatively small number of species, predominance of shrubby habit, and scarcity of arboreous forms, and the presence of sharply marked growth rings in the few trees that are known, are facts which lend support to the prevalence of a cold temperate climate in Gondwanaland. The emergence of so many new genera and species which are radically different from the arborescent Carboniferous plants is possibly due to mutations which occurred on a large scale. As Sahni observes ' Exposure to the rigours of the climate had quickened the pace of evolution, as if by inducing saltations on a large scale, a sort of natural vernalization, affecting not only the individual life-cycle, but also the rate of evolution of species, possibly through aberrations in the nuclear cycle'

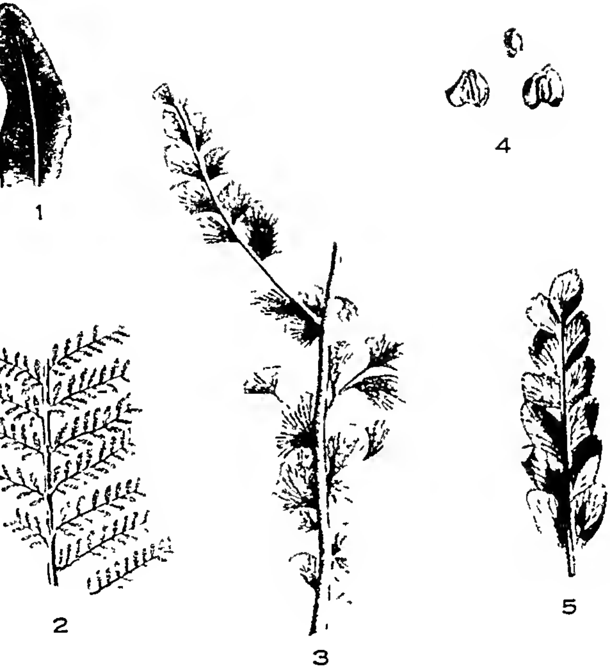
Besides the pteridosperms conifers were represented by *Buriadia*, *Paranocladus* and *Walkomiella* and *Dadoxylon* woods some of which might have belonged to Cordaitales

The Equisetales were represented by species of *Schizoneura*, which had longer and broader leaves as compared with *Calamites* No true *Calamites* have been recorded from Gondwanaland. *Phyllotheca* was another representative of the Equisetales It was a small plant with jointed stem and cup-like whorls of leaf-sheaths cut into short linear segments

Only a few of the Permian fossil plants from India, South Africa, South America and Australia resemble those of the northern hemisphere Trees common to the floras of the northern hemisphere and Gondwanaland are *Lepidodendron* *Sigillaria*, *Psygmophyllum*, *Sphenophyllum* and *Psaronius* Strap-like leaves resembling those of *Cordaites*, described as a species of *Noeggerathiopsis* have also been described from Gondwanaland. *Dadoxylon indicum* is the stem of a member of Cordaitales, which shows well-marked annual rings. These stems have been recorded from India, Australia and South America

Courtesy Birbal Sahni Institute of Palaeobotany, Lucknow

A PALAEOSCAPE OF GONDWANALAND IN THE PERMO-CARBONIFEROUS, SHOWING CLUMPS OF GANGAMOPTERIS AND GLOSSOPTERIS WITH A GROVE OF CORDAITES TO THE RIGHT



Courtesy GSI Calcutta

SOME PERMIAN PLANT FOSSILS FROM THE PANCHET HILLS, BIHAR

1. *Oleandridium* cf. *eurychoron* Schenk, 2. *Pecopteris concinna* Presl. 3. *Cyclopteris pachyrhachis* Gopp. 4. *Samaropsis* sp., 5. *Dicroidium* cf. *odontopteroides* (Morris) Gothan

Kusnetzk Flora of Angaraland

Kusnetzk flora, named after Kusnetzk in Siberia, had many peculiarities, and its plants differed in many aspects from the Permo-Carboniferous vegetation of North America and Europe. One of the most typical genera of the Kusnetzk flora is *Callipteris*, a pteridosperm With *Psygmophyllum* and conifers like *Ullmannia*, *Walchia*, and *Dicranophyllum*, there also occurred plants allied to *Ginkgo*, like *Ginkgoites*, *Phoenicopsis*, and *Czekanowskia*, together with plants characteristic of early Mesozoic like *Podozamites*, *Cladophlebis* and *Baiera* Gondwanaland genera like *Gangamopteris* also occur in Kusnetzk flora of Angaraland In fact the significant features of the Angaraland vegetation are the admixture of the Gondwanaland forms, and plants characteristic of the early Mesozoic flora The presence of forms like *Gangamopteris* in Angaraland indicates that chains of islands must have existed in the Tetbys Sea between Gondwanaland and Angaraland, which enabled some of the plants of Gondwanaland to migrate to Angaraland This has been confirmed by the work of Wadia in Kasbmir and of Mushketov in north of Pamir plateau In eastern Farghana, between the meridians of 70° and 75°, Mushketov found evidence of many isolated dome-like elevations only 16 to 80 km apart, which represent the remnants of the archipelago of islands which served as stepping stones for Gondwana plants migrating to the north

Advances in Plant Life

The succession of diverse climatic conditions, the segregation of the late Palaeozoic flora into floristic provinces geographically separated from one another by marine barriers and the impact of the local physiographical features resulted in the new kinds of plants with new adaptations Many changes had occurred before the Permian Period drew to a close The glory of the arborescent lycopods had departed, and *Sigillaria* and *Lepidodendron* had disappeared, and the same fate had overtaken *Sphenophyllum* and numerous species of *Calamites* Pteridosperms also dwindled and vigorous members of this group, like *Neuropteris*, *Alethopteris* and *Medullosa* also failed to survive However, it is likely that some of the pteridosperms evolved into the ancestors of the present day flowering plants, and in the modified form passed on into the Mesozoic Era Climatic changes may have forced the pace of evolution, and perhaps as Wells and Huxley believe that it was the stress and pressure of increasing aridity coupled with cold which forced some seed-bearing members of the *Glossopteris* plant-army on to the further pitch of dry land adaptation, which from the Trias onwards, embodied in the cycads and conifers, dominated the vegetable world Strides in evolution towards angiospermy seem to have taken place in the Permian, although the actual birth of the vast group of angiosperms took place about a hundred million years later

With the dichotomous leaves and the sporangiophoric trusses, *Trichopitys heteromorpha* is considered the ancestor of the modern *Ginkgo* (Fig 47)

The evolution of the modern conifer seed-cones consisting of spirally arranged bracts and ovuliferous scales from the late Palaeozoic conifer seed-scale complexes was a great step A seed-scale complex in the early conifer cones consisted of a bifurcate bract bearing in the axil several spirally arranged appendages, either all sterile but one fertile having an erect ovule as in *Lebachia*, or several or all fertile, each bearing an erect ovule as in *Ernestiodendron* (Pl. 40). Erect ovules in *Lebachia geoppertiana* were borne on the inner side, probably suggesting here a shift to flattening and bilateral symmetry, but the ovules in *Ernestiodendron* and some species of *Walchiostrobus* were inverted with the number of fertile scales reduced in the latter In *Pseudovoltzia libeana*, there were only five sterile scales, and three fertile scales each with an inverted ovule. *Glyptolepis* had only two inverted ovules per seed-scale complex. All the five sterile scales in *Ullmannia* were

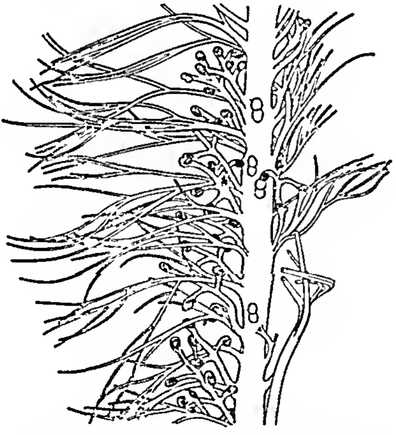
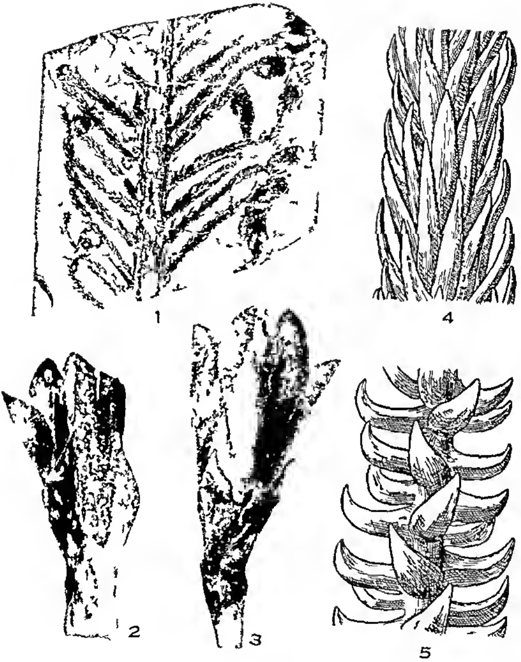


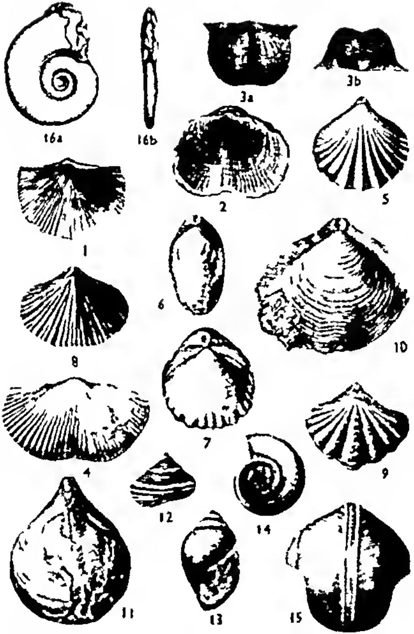
FIG. 47 A SHOOT FRAGMENT OF *Trichopitys heteromorpha* WITH LEAVES BEARING SEED-BRANCHES IN THEIR AXILS. This plant is the possible ancestor of the maiden hair tree, *Ginkgo biloba* (After Florin)



After Flor i

SOME FOSSIL CONIFERS THESE ARE POSSIBLE ANCESTORS OF THE PRESENT DAY CONIFERS LIKE MEMBERS OF TAXODIACEAE CUPRESSUSACEAE PINACEAE ETC.

1 *Lebacl a p for* w tl term nal seed cones 2 & 3 Seed co es of *L p fo m s* 4 The arrangement of leaves in *L p fo s* 5 Lea es of *E od l o fil fo ne*



Courtesy GSI Calcutta

SOME PERMIAN ANIMAL FOSSILS FROM INDIA AND NEIGHBOURING COUNTRIES

1 Streptorhynchus (Schuchertella) purdoni Reed 2 *Productus* (*Dictyoclostus*) gratiosus Kutorga 3 (a b) Marginifera ... Dien 3a dorsal view 3b apical view 4 *Chonetes* (*Pl. ...chonetes*) ...mulata Reed 5 *Rhynchonella* ? ...lata Reed 6 *Dielasma* ... Waag 7 *Notothyris* ... Reed 8 *Spirifer* (*Purdonella*) ... Reed 9 *Spiriferina* ... var ... Reed 10 *Athyris* (*Cleiothyridina*) ... Reed 11 ... Waag 12 *Pleurotomaria* (*Phymatopleura*) ... Reed 13 *Macrocheilus* (*Sphaerodoma*) cf ... Meek & Worthen 14 *Euomphalus* (...) ... Reed 15 *Bellerophon* ... Reed 16 (a b) ... carbonaria Waag
(1 11 Brachiopoda 12 15 Gastropoda 16 Cephalopoda)

fused to form a single scale, bearing a single fertile appendage with an inverted ovule—a situation closely approaching the modern conifer seed-cones

The disappearance of the forked nature of the bract, the reduction of the sterile scales to five and their ultimate fusion, the reduction of the fertile scales to one, and the inversion of the ovules are the steps pointing to the evolution of the seed-scale complexes of modern conifers from that of their Permian ancestors

ANIMAL LIFE

Invertebrates

The rise of land in the form of vast continental areas and succession of diverse climates in the Permian also affected animal life The invertebrates suffered many changes Cystoids, trilobites and eurypterids almost became extinct. *Phillipsia* and *Cheiropyge* were the only survivors of the once dominant trilobites Foraminifers, abundant in the preceding period, were of common occurrence Declining trends in crinoids resulted in their considerable diminution, though in Permian seas of Gondwanaland they were plentiful Radiolarians, sponges and echinoids continued to be present, though much reduced Besides the ancient Tetracoralla, which were still common, corals of the Hexacoralla type made their first appearance Brachiopods and gastropods were common Cephalopods became more complex The increasing trend in pelecypods resulted in their great numbers and species and bryozoans became abundant Ostracods continued to be abundant Some of the Permian animal fossils from India and neighbouring countries are shown in Pl 41

The veritable submarine forests at the bottom of the shallow seas were largely constituted by brachiopods and other fixed forms of life, such as Bryozoa together with a proportionately large pelecypod component There were several kinds of brachiopods, such as the orthid brachiopods having shells with well developed teeth and sockets for the articulation of the valves (*Enteletes*), the strophomenid brachiopods in which one valve is distinctly concave (Productidae), those with prominent pointed beaks (Terebratulid-type) and the highly developed spire-bearing brachiopods (Spirifers) Many members of the Productidae were characterized by prominent radiating ribs and crossed wrinkles bearing numerous long hollow spines Of the two highly specialized forms, *Richthofenia* resembled more a horn coral than a brachiopod and from it arose lamellibranchs of Hippuritidae group later, the other, *Leptobolus* was also very much unlike any other brachiopod. *Lyttonia* and *Oldhamia* were the other strange and aberrant forms The spire-bearing brachiopods were very highly evolved of their class, with plications arranged in bundles, both on the fold and sinus. Their shell structure and internal features were better organized as compared with the members of this class in the preceding geological periods

Amongst the cephalopods, the ammonoids showed a progressive increase of sutural complexity and varied ornamentation

The distant relatives of the modern spike-tailed king crab, *Limulus*, can be recognized in some Permian eurypterids

Insects, which had become fairly abundant in the Carboniferous, were represented by dragon-flies with a wing-spread of 70 cm, and cockroaches several centimetres long However, the higher types of insects, such as bees and butterflies had not appeared as yet. With the disappearance of swamps and lagoons, and humid forests, only those forms could go ahead which were more adapted to life on dry land.

Vertebrates

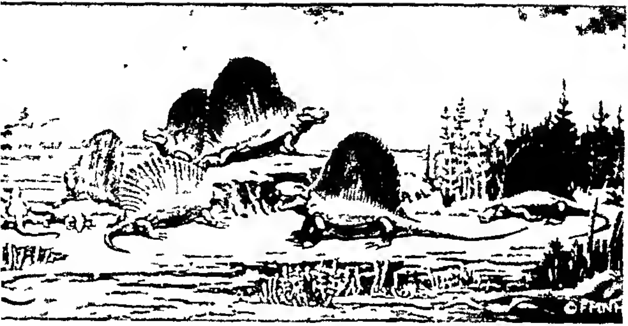
Amphibians, which appeared in the late Devonian and were predominant in the Carboniferous, were represented by various genera, but could not march forward Many of them retreated to rivers and lagoons Most of them were broad and short-legged forms The stegocephalians also lingered on, till they perished on account of mounting cold and aridity

Advances in Animal Life—The Rise of Reptiles and Birth of Mammals

With the advent of dry conditions, a premium was set on the development of full adaptation to dry land. As a result, the reptiles which developed a covering of thick scales to protect their bodies against the dangers of desiccation, had an advantage over slimy and thin-skinned amphibians The true reptiles in fact evolved from the creeping amphibians In Amphibia, the limbs act more as oars for propelling the body in the watery medium and as such they protrude sideways In reptiles, due to more efficient use, limbs become pillar-like supports for the body. Another achievement of the reptiles was the elimination of tadpole stage from their life-cycle and the development of the shelled egg Thus, they became more independent of the ancestral watery environment The shelled egg gave the same benefit to animals as the evolution of the seed to plants The shelled egg with tight packed yolk surrounded by an extra layer of food in the form of a layer of white, and amniotic fluid, all enclosed in a tough drought-resisting shell, conferred many advantages on their reptilian possessors They could lay their eggs on land, unlike amphibians, who must lay theirs in water Thus, they dispersed their kind all over the surface of the dry land Internal fertilization also became a necessity with shelled eggs, and thus love and courtship developed, for a female must be courted and won It was also an economy in the sense that fewer eggs need be produced.

Cour[illegible]y American Museum of Natural H[illegible]ry, New Yo[illegible]

RESTORATION OF SEYMOURIA ONE OF THE MOST PRIMITIVE REPTILES



Painting Charles R. Knight. Courtesy Chicago Natural History Museum

A PALAEOSCAPE OF THE PERMIAN PERIOD

Various pelycosaurs are shown. Some of them had large fins, others were essentially like lizards. In the right foreground are two salamander-like amphibians, with flat, horned skulls

Scaly covering of the body and shelled egg were the hall-marks of success of the reptiles, which arose in the Permian Period and developed into various forms Genera, like *Limnoscelis*, had weak legs protruding at sides The most primitive Permian reptiles were the cotylosaurs Pl 42 shows the restoration of *Seymouria*, one of the most primitive reptiles *Pareiasaurus* was a heavy vegetarian form with pillar-like legs Most remarkable were the pelycosaurs, the ship-lizards, with spine-like growths on their backs, rigged in the form of a sail (Pl 43) These ship-lizards were represented by forms, like *Naosaurus* and *Edaphosaurus*, some of which were 2 4 m. long, in some of these the bony spikes of their sail-like growths also had side-spikes

The most promising group of Permian reptiles were the theriodonts the first vertebrates to develop teeth which could be classified into groups as in mammals, such as molars, canines, and incisors It is likely that smaller forms among these were the ancestors of mammals

CHAPTER ELEVEN

THE TRIASSIC PERIOD

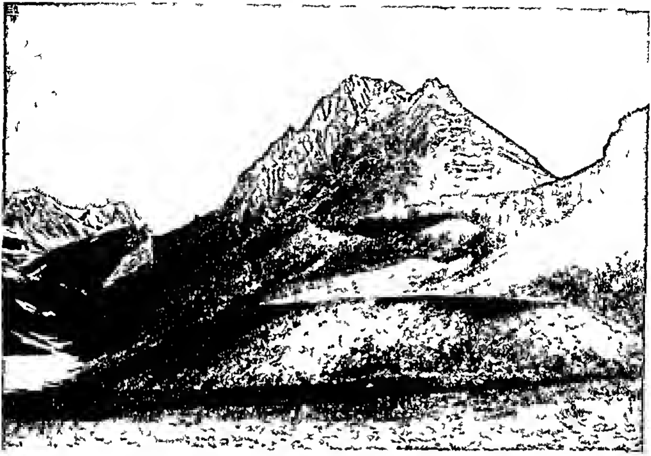
The Age of Pteridosperms and Conifers, Dinosaurs and Theromorphs

AFTER THE CLOSE of the Palaeozoic Era commenced the Mesozoic—an era of transition between the Palaeozoic and the Cenozoic which continued for about 120,000,000 years A large part of eastern India from the Rajmahal hills in Bihar through Damuda, Mahanadi and Godavari valleys to the neighbourhood of Madras, the Satpura hills, Kathiawar and Kutch in the west, and Madhya Pradesh and the Deccan were formed in this era Marine deposits were laid in the north-west India in present day Spiti, Garhwal Kumaon and Kashmir, in the Salt Range and Baluchistan areas of Pakistan, and in Burma Besides, several marine transgressions, some of them affecting the heart of the peninsula, and volcanic eruptions took place in the later part of this era which find no parallel in the modern world. Life was of an intermediate character Palaeozoic forms gradually declined and became extinct while several new forms emerged, showing more kinship with the modern ones

Of the three sub-divisions of the Mesozoic Era, viz Triassic, Jurassic and Cretaceous, the Triassic, lasting for about 40 million years, ended about 140 million years ago The Triassic Period derives its name from the three-fold development of rocks of this period, namely the Bunter, the Muschelkalk and the Keuper which were first studied in the Alps All important divisions of the Triassic system are represented by marine strata in central and southern Europe

In India, the three well marked sub-divisions of the Triassic Period are recognizable in the 900 m. thick deposits in Spiti, Garhwal, Kumaon (Pl 44) and Kashmir, where this enormous development of the Triassic system is continuous with the Palaeozoic deposits as in other parts of the world The Triassic rocks occur along the entire northern boundary of the Himalayas constituting the great scarps of the plateau of Tibet At Lilang in Spiti, a complete section is exposed showing a succession from the Permian to the Jurassic rocks. These marine rocks mostly comprise variegated shales, slates, limestones, dolomites, calcareous shales and the red sandstones intercalated with layers of rock salt, gypsum, alabaster and partly coloured sands or clays

The terrestrial rocks of this period are found in the Satpura and Godavari regions,



Courtesy GSI Calcutta

TRIASSIC FOLDS, NORTH OF DAWE CAMP, DARMA, KUMAON

and comprise massive red and yellow coarse sandstones, conglomerates, grits and shales, without any carbonaceous matter. They are typically developed in Pachmarhi and Mahadeo hills in Satpura range where they are 900 to 2400 m thick. The Panchet Series of rocks are made up of fine red clays and coarse micaceous sandstones and are about 450 m thick. On top of the Mahadeo Series are the Maleri Series of rocks, which are restricted to Satpura and Godavari regions. The successional order in which these rocks are known comprises Panchet Series, Mahadeo Series and Maleri Series.

Triassic rocks in other parts of the world are made up of marine deposits, salt beds, red beds, gypsum, limestones, sandstones, gravels, clays and volcanic deposits. Coal deposits of upper Triassic occur in Austria, Virginia and New Carolina in USA, and in some other places.

Palaeogeography

Although still girdling the world, the Tethys Sea had considerably receded. It temporarily withdrew from the Salt Range after the middle Triassic and an effective barrier existed between the seas of Kashmir and Spiti during the upper Triassic. This barrier interrupted the free movement of species between the two areas. The occurrence of foreign limestone blocks allied to the Trias of the eastern Alps, mixed up with blocks of foreign Permian to Cretaceous limestones, in the Tibetan border of Kumaon is believed to be due either to shattering by explosive volcanic action and transport by lava flows or to an overthrust sheet from a northern region, detached by denudation into isolated masses.

A broad sea, however, existed in southern Europe where enormous masses of limestone made up of corals and calcareous marine algae are found. A marine invasion in North America spread over the region now occupied by the Rocky Mountains (Fig. 48). The great basic volcanoes were active in the eastern part of North America and a great deal of lava was poured out into a large syncline. Sandy plains studded with salt lakes emerged as a result of the gradual uplift.

The desiccation which started in the Permian reached its maximum during the Triassic. Large deposits of salt and gypsum and extensive areas of red beds reveal widespread aridity of climate. Owing to higher evaporation than precipitation, the inland seas were heavily laden with salts and a warm climate prevailed in the northern continent. The presence of corals and marine algae also suggests the occurrence of a warmer climate in the northern continent. Fossil evidences suggest that the water of the Arctic Sea was cooler than that of lower latitudes. The climate in the Gondwanaland is believed to have been dry and temperate. Coal deposits in some parts of the world such as lower Austria, and Virginia and North Carolina, suggest the prevalence of a favourable climate.

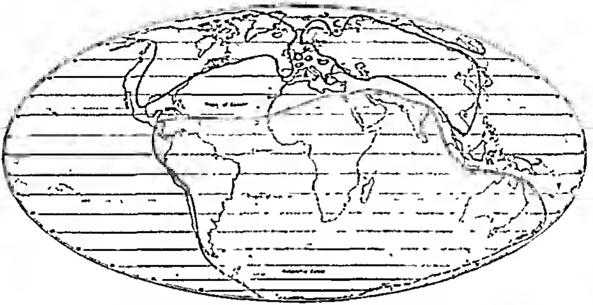


FIG. 48. MAP OF THE WORLD AT THE END OF THE TRIASSIC PERIOD. The shaded areas are land (After Arldt)

PLANT LIFE

The early Triassic plant life was more closely linked with that of the late Palaeozoic, although in contrast to now wholly extinct forms of life in the late Palaeozoic, it largely consisted of such forms in which the precursors of more familiar and modern forms become recognizable. The preliminary steps towards modernization, however, commenced towards the close of the Palaeozoic. Similarly, possible ancestors of the present day mammals were the predominant animals in the Triassic fauna. Fig. 49 gives a Triassic landscape showing the dominant plants and animals.

Liverworts and Mosses

A small dichotomously branching thallus, *Ricciopsis florinii*, showing a rosette-like growth, is known from the upper Triassic coal mines of Sktomberga, Sweden. The mosses were represented by *Naiadita lanceolata*. The unbranched small plants bore spirally arranged lanceolate leaves, less than 5 mm long. Besides gemmae, archegonia have also been found. The sporophyte had a short bulbous foot and a globose sporogonium which produced lens-shaped spores. Leaves were without midrib, rhizoids were unicellular and there was one-layered venter in the archegonium. The stems were without differentiation into tissues.

Lycopods

The low growing herbaceous lycopods of the Triassic, *Selaginellites* and *Lycopodites* resembled modern *Selaginella* and *Lycopodium* *Selaginellites polaris* from the Triassic of Greenland bore cones upto 7 mm in diameter The megasporangia contained many megaspores which were much larger than the microspores Dimorphic foliage is known in *Selaginellites hallie* from the Rhaetic of Scania, Sweden The *cones were comparatively* smaller than in *S polaris*, with only four megaspores in each megasporangium.

The arboreal lycopods were represented by Pleuromias which were somewhat similar in habit to that of Palaeozoic Sigillarias The stems were unbranched and about 2 m high and upto 9 cm thick The leaves, about 11 cm long and 1 5 cm broad were ligulate, with a broadly flaring base, and were loosely arranged on the stem Two vascular bundles traversed the leaf The root system was four-lobed and raised upward The stem

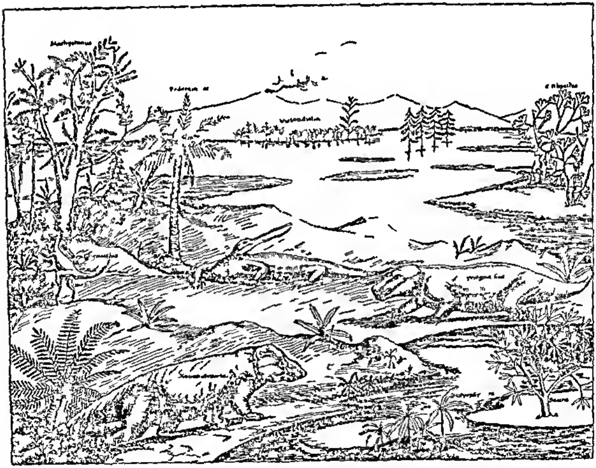


FIG 49 A TRIASSIC LANDSCAPE SHOWING THE DOMINANT PLANTS AND ANIMALS

terminated in a cone and the plants were heterosporous The sporangia were abaxially attached.

Articulates

The vast group of the Palaeozoic articulates was very scantily represented in the Triassic Equisetaceae was represented by the genus *Equisetites*, which in many respects is closely related to modern *Equisetum* except for the large size *E platyodon* had a diameter of 6 cm Calamitaceae had become extinct, but some Sphenophyllales did exist in the early Triassic *Schizoneura* and *Phyllotheca* extended from the Palaeozoic to the Triassic

Ferns

Some members of Palaeozoic Marattiaceae such as the genus *Asterotheca* extended into the Triassic. *A meriani* from the Triassic of Lunz, Austria, was very much similar in habit to the Carboniferous plants *Marattiopsis hoerensis* from the Rhaetic of Greenland, is closely comparable with some modern species of *Marattia*

Gleicheniaceae was represented by *Gleichenites* and *Mertensites* Matoniaceae was represented by *Phlebopteris* and *Matonidium* The fronds in both were large and resembled those of modern *Matonia* Both *Gleichenites* and *Matonidium* were of rare occurrence Dipteridaceae was another family with large fronds *Clathropteris meniscoides* from the Rhaetic of Greenland had a blade about 35 cm in breadth with 10 or 12 divisions and net venation made up of large rectangular meshes Osmundaceae was represented by *Cladophlebis* and *Todites*

Pteridosperms

Corystospermaceae and Peltaspermaceae the two families of this vast Palaeozoic group are known from the Triassic Leaf impressions like *Thinnfeldia* and *Dicroidium* are also believed to belong to this group, although evidences are lacking The genera *Glossopteris*, *Pecopteris* and *Cyclopteris* extended from the Palaeozoic into the Triassic

The vegetative and fertile remains comprising the Corystospermaceae are exclusively known from Natal South Africa Their close association and similarity in cuticular structure justify their assemblage in this family The foliage is believed to have been represented by *Dicroidium*, *Stenopteris* and *Thinnfeldia* The pollen bearing organs *Pteruchus africanus* consisted of dichotomously divided branch system with each branch terminating in circular or elliptical lamina which bore sporangia on the entire undersurface and produced winged pollen The female infructescence, *Umkomasia macleani*, bore lateral branches in one plane, in the axils of bracts each branch having a pair of

small scale-like structures and several terminal one-seeded, bivalved and helmet-shaped cupules. In *Pilophorosperma granulatum*, the micropyle, curved and bifid at the tip, projected from the cupule which was lined with hairs. The branches were spirally arranged in *Spermatocodon*.

Zuberia zuberi was another distinctive member of this group, known from Argentina. In it, the sterile fronds divided dichotomously and the pinnules were like those of *Odontopteris*. The dichotomously branched male fructification had stalked appendages on which sporangia were attached at right angles. The cupulate organs were somewhat like those of *Umkomasia* (Fig. 50).

Peltaspermaceae, another family of Triassic pteridosperms, is known from the Rhaetic of Greenland and the late Triassic of Natal. It had long fern-like fronds referred to the genus *Lepidopteris*, of which *L. natalensis* is from Natal and *L. ottonis* from east Greenland. The bipinnate frond had small blister-like swellings on the rachis It closely resembles the Palaeozoic *Callipteris*. The microsporangia were borne in pairs on the

FIG 50 *Zuberia zuberi* 1, A sterile frond, 2, Reconstruction of the male fructification, 3, Cupulate organs (After Frenguelli)

ultimate branches of a pinnately branching structure their mode of dehiscence was longitudinal The branching was three-dimensional The seeds attached on the under-surface of a peltate cupule disc, were oval, with curved micropylar beaks

Cycadeoids (Bennettitales)

Wielandiella angustifolia from the late Triassic of Scania Sweden, was a delicately branching plant The apical growth was terminated by a fructification the central axis of which bore several ovuliferous scales and small seeds The stem is believed to have borne about 8 cm long leaves called *Anomozamites minor* which enclosed the fructification by their winged petioles and bracts (Fig 51 2)

In *Sturiella langeri*, a small and delicate plant from the Triassic of Lunz, Austria, the axis was about 4 cm long and the slender lateral branches terminated in fructifications looking like small heads of a sunflower The central part of the fructification was ovulate, surrounded by 25–30 ray-like lobes, each bearing a sporangium or coalesced

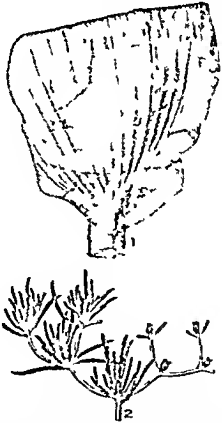


Fig 51 1 *Sanmiguelia lewisi* a leaf of a presumed Triassic palm from Colorado (After Brown) 2 Restoration of *Wielandiella angustifolia* from the late Triassic of Scania Sweden (After Nathorst)

sporangia attached to the inner edge at the base of each ray Several leaves of *Otozamites* and *Anomozamites* have also been found. The genus *Pterophyllum* was a common constituent of the bennettitalean plant life of this period

Cycads

A late Triassic genus, *Cycadospadix*, shows a close resemblance to the megasporophyll of *Cycas* but the epidermis is bennettitalean No seeds have been found attached Perhaps it was a bract of a bennettitalean inflorescence But *Palaeocycas* from the Rhaetic of Sweden, had epidermis, like that of Cycadales It is very much like *Cycadospadix* but for the broad entire-margined apex Seeds were perhaps borne on lateral projections of the slender stalk The fructifications, comprising spirally arranged megasporophylls (*Palaeocycas*), were borne on straight, columnar and unbranched trunks, about 3 m high, called *Bjuvia simplex*, terminating at the top in a crown of *Taeniopteris* leaves

Cordaites

The only survivor of this dominant Palaeozoic group, *Noeggerathiopsis* (*Cordaites*) *hislopi*, existed in the lower Triassic of Gondwanaland

Ginkgoes

Both the genera, *Ginkgoites* and *Baiera*, were well represented during the Triassic. Leaves referred to the genus *Ginkgoites* are wedge-shaped or broadly obcuneate with a notch or divided into lobes of equal size, but in *Baiera* and allied genera, the lamina is cut into narrow slender segments The leaves in *G lunzensis* were borne on short shoots. *Sphenobaiera furcata*, which extended from the lower Permian to lower Cretaceous, had many characters in common with the lower Permian *Trichopitys heteromorpha*, except that the leaves were arranged on short as well as long shoots The microsporangiate organs were borne on short shoots The sporangia were disposed in clusters of three to five on the bifurcated branches arising from the central axis (Fig 52,6-9)

Conifers

The genus *Glyptolepis* of Permian extended into the Triassic. The bracts were not dichotomous and the seed-scale complex consisted of five or six sterile scales each bearing two megasporophylls with an inverted ovule In *Voltziopsis* from East Africa, the seed-scale complex had two-forked bracts five to six partly fused scales, and five stalked megasporophylls each bearing one erect terminal ovule. It showed characters of the seed-scale complex of *Lebachia* of Palaeozoic The lower Triassic *Voltzia* had unforked bracts and five equal sterile scales fused with the stalk-like megasporophylls The upper Triassic

Schizolepis was very much like *Voltzia* but had three sterile scales and three megasporophylls united in their basal parts The upper Triassic *Cycadocarpidium* bore seed-scale complexes in the axils of large, parallel-veined bracts each with two distal sterile scales and two basal megasporophylls with an inverted ovule in each

Palissya and *Stachyotaxus* were unique conifers In *Palissya* the seed-scale complexes were borne in the axils of entire bracts and not completely united with them There were about ten megasporophylls, each carrying one terminal inverted ovule surrounded by a cup-shaped aril. *Stachyotaxus* had only two megasporophylls to each bract. The terminal and slightly inverted ovule was surrounded by free aril

Fossil woods showing araucarian pitting and those comparable to *Cedrus* (*Cedroxylon*) were the other conifers in Triassic. *Woodworthia arizonica*, although araucarian in anatomy, had persistent short shoots as in Abietineae

Taxads

The upper Triassic *Palaeotaxus* consisted of a short, radially symmetrical, lateral shoot. It bore spirally arranged sterile scales and terminated in an atropous, erect ovule or seed enveloped in an aril and surrounded by the uppermost scales

Besides the gymnosperms described above, there were some other forms of plant life which are difficult to assign to any known natural orders The genus *Rhexoxylon* with three species *africanum*, *tetrapteroides* and *priestleyi*, the first from Antarctica and the others from South Africa, comprised trunk fragments upto 3 m. long and 5 0–16.5 cm in diameter The large parenchymatous pith was surrounded by a ring of small steles The wood was typically coniferous in character *Rhexoxylon* was perhaps liana-like in habit.

The upper Triassic *Hydropteridangium marsilioides* Halle from Bjuf Sweden now transferred to the genus *Harrisia* consisted of a long axis bearing lateral branches in all planes each of which divided in a three-dimensional pattern and bore two-valved capsules Seven elongate sporangia were present on the inner surface of each valve The microspores were winged Associated with these occurred fronds of *Ptilozamites* which had cuticular similarities with *Hydropteridangium*

Angiosperms

The Triassic plant fossils also include some forms which look like angiosperms The fruits *Fraxinopsis major* and *F minor* from the Rhaetic of south-west Mendoza, Argentina have been compared with those of Ash. *Furcula granulifer* from the Rhaetic of Greenland looks like a dicotyledonous leaf *Sanmiguelia lewisii* from the Triassic of Colorado is like a palm leaf (Fig 51 1)

Some of the Triassic fossils of Glossopteris flora are given in Fig 52.

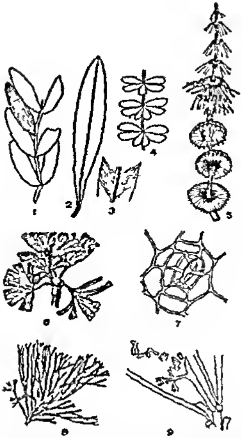


FIG 52. SOME OF THE TRIASSIC FOSSILS OF THE GLOSSOPTERIS FLORA. 1. *Schizoneura gondwanensis*, 2 & 3, *Glossopteris* sp: 2, a leaf, 3, a portion of the leaf enlarged to show venation 4, *Sphenophyllum speciosum*, 5. *Phyllotheca etheridgei*, 6 & 7, *Ginkgoites lunzensis* 6, a short shoot with leaves, 7, stoma, 8 & 9, *Sphenobaiera furcata* 8, a long shoot with leaves, 9, a portion of short shoot with fragmentary microsporophyll (1, after Feistmantel, 4, from a specimen in the British Natural History Museum, 5, after Saksena, 6-9, after Kräusel)

Advances in Plant Life

The plant life during the Triassic had considerably changed from that of Permian. The vast group of articulates had been reduced to a few genera. *Equisetites, Phyllotheca* and *Schizoneura* continued from the Palaeozoic. *Equisetites* was more like modern *Equisetum*, though still larger in diameter. The arboreal lycopods had been replaced by the herbaceous forms, which were not very different from modern *Selaginella* and *Lycopodium*. But Pleuromias still emulated the habit of Palaeozoic Sigillarias. The large population of Palaeozoic ferns was considerably reduced. Marattiaceae and Gleicheniaceae were rare, and Dipteridaceae and Matoniaceae were also not so common. This must have happened in response to arid climate in the Triassic. *Asterotheca*, however, did pass over to the Triassic from the Palaeozoic. The Triassic ferns also showed much modernization.

Pteridosperms, a dominant group in the Palaeozoic, were commonly represented; some, like members of Glossopterideae, continued from the Palaeozoic, but others were new. The Triassic pteridosperms had no close correlation with those of the Carboniferous. Clear homology, however, can be seen between the helmet-shaped organs of the Corystospermaceae with the cupules of Palaeozoic pteridosperms; even the male organs seem to be similar in plan to those of *Crossotheca*, but the seed-bearing appendages in Peltaspermaceae record a striking departure from this group.

A new group that emerged during the Triassic was Bennettitales, the representatives of which were delicate and had characteristic fructifications. The seeds were aggregated, along with sterile scales, into a head. The Cycadean foliage had been known earlier, but forms approaching the modern cycads appeared in the Triassic.

Differentiation into short and long shoots in the Ginkgoales became more eviden during the Triassic. The evolution of this vast group from the Permian *Trichopitys* extended into the Triassic *Sphenobaiera*.

The evolution in the seed-scale complexes of conifers showed further strides. *Glyptolepis* showed reduction in the number of megasporophylls, and the bracts became entire, although *Lebachia*-like seed-scale complexes still existed, as in *Voltziopsis*, in which partial fusion of the sterile scales had been achieved. The fusion of the stalks of megasporophylls with the sterile scale was achieved in *Voltzia*. The reduction of sterile scales and megasporophylls from five to three is seen in *Schizolepis* and to two in *Cycadocarpidium*.

Amongst the interesting new conifers in the Triassic may be mentioned *Palissya* and *Stachyotaxus*. In the organization of flowers they are different from other conifers. In having almost completely fertile flowers, *Palissya* seems to retain the characters of *Ernestiodendron* rather than those of *Lebachia*. In the reduction of megasporophylls, *Stachyotaxus* is more advanced over *Palissya*.

The reduction of the female inflorescence from an aggregation of flowers to a solitary flower in gymnosperms, was also achieved during the Triassic, as is evidenced by the genus *Palaeotaxus* in which the solitary flowers occur in the axils of either foliage leaves or scale-like leaves on long shoots. This gave rise to a new group of gymnosperms, the taxads.

Rhexoxylon and *Hydropteridangium*, the strange gymnosperms, were perhaps of transitional nature. *Rhexoxylon* had characters of Medullosae and conifers, and of some modern angiospermous lianas, such as *Tetrapteris*, *Banisteria* and *Wilbrandia*. *Hydropteridangium* had characters in common with *Marsilea*, cycads and conifers. Although clearly gymnosperms, they were perhaps aberrant forms of the Triassic plant life.

There was perhaps a sprinkling of angiosperms too during the Triassic, if *Sanmiguelia lewisii* from the Triassic of Colorado is really a palm. *Furcula granulifer* may also be

suggestive of that, if proved to be an angiosperm The same may be said about *Fraxinopsis*

ANIMAL LIFE

Like plant life, animal life during the Triassic was also varied and consisted of many new forms Several groups of animal kingdom continued into the Triassic from the Palaeozoic, but most of them lacked archaic characters

Invertebrates

Foraminifers and radiolarians were present Sponges were also present and were much diversified The modern types of corals which began very late in the Palaeozoic became quite abundant, especially hexacoralla The Palaeozoic tetracoralla became extinct

All the important sub-divisions of echinoderms were present. The stone lilies (the stalked forms) exhibited a more modern aspect The asterozoans had already become distinctly modern Echinoids, the sea lilies, were well represented. Bryozoans were present but brachiopods decreased considerably in the number of species and individuals, and those with curved hinge-lines increased over those with straight hinge-lines

Molluscs on the whole were a dominant group of animals Amongst them the pelecypods were mostly modern in aspect. Gastropods also became common and showed the same trend towards modernization The Triassic fauna of the Himalayas is particularly rich in number and variety of cephalopod fossils According to Wadia, it forms the richest and most widely spread fossil horizon in the central and north-western Himalayas The most typical fossils belong to genus *Ceratites* and ammonites belonging to the genera *Nautilus, Xenaspis* and *Orthoceras* The Saligram stones are fossils of ammonites, and are brought to Hardwar by Sadhus from Byans and Johar in Kumaon The sutures between the chambers of Triassic ammonites had become very complex, as compared with simple partitions of the shells of Palaeozoic ammonites In fact, the presence of ammonite shells with complex sutures, is taken as an index of the age of rocks, when such fossils are discovered it indicates that the rock in question is Mesozoic rather than Palaeozoic Bivalves are represented by *Daonella* and *Halobia* There is great resemblance between the cephalopod fossils of the Triassic rocks of the Himalayas and Alps and many species are common This is explained by the fact that both these areas were washed by the waters of the Tethys Sea which also provided a free channel of migration for the marine animals from the eastern coast of China to the Mediterranean shores of France.

Amongst the cephalopods, the straight-shelled nautiloids became extinct during the Triassic, but the coiled forms increased as compared to the late Palaeozoic The ammonites

developed much greater complexity of shell structure. Forms like Palaeozoic *Goniatites*, were still present. Forms with slightly serrated sutures or partition structures, like *Ceratites*, *Meekoceras koninckianum* Waag *Otoceras clivei* Dien, *Ophiceras sakuntala* Dien and *Ptychites cognatus* Oppel appeared in this period. Later, the most complex-chambered cephalopod, *Rhynchonella trinodosi* Bittn appeared before the close of the Triassic. The highest of all the molluscs, the dibranchs including modern cuttlefishes also appeared during this period. The conical *Belemnites* was very similar to modern cuttlefish

Trilobites amongst the crustaceans, an important group of animals during the Palaeozoic, became extinct before the beginning of the Mesozoic. The decapods appeared in the Triassic. They were long-tailed animals Insects which were common were mostly of the simpler forms and beetles became abundant.

Some of the Triassic animal fossils from India and neighbouring countries are shown in Pl. 45

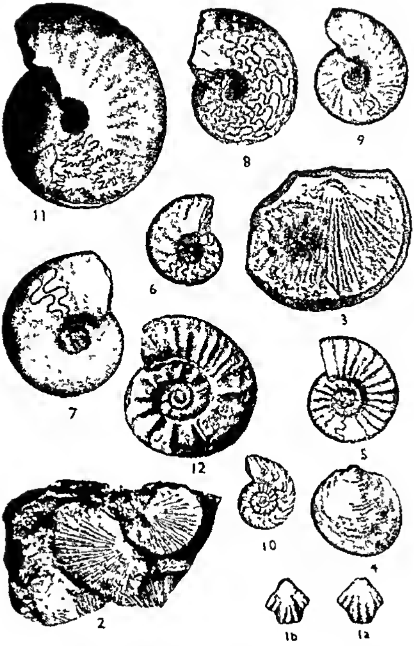
Vertebrates

Fishes were as abundant as in the late Palaeozoic and they included selachians, dipnoans and ganoids

Large foot-prints of extinct amphibians are occasionally seen on Triassic sediments These are the tracks of animals, who walked over the soft sandy soils bordering the salt lakes In many cases these extinct animals did not leave any bones, and footprints are the only records Fossils of large amphibians, some of them nearly 3 m long, with skulls 75 cm long and 45 cm broad have been found in the Rocky Mountains of America These amphibians were unprotected on the back, though heavily armoured on the ventral side They were slow moving clumsy creatures and fell an easy prey to more agile carnivorous reptiles.

Stegocephalan labyrinthodonts belonging to the genera *Gonioglyptus* and *Pachygonia* have been discovered from Panchet Series of rocks of middle Gondwanas, and *Brachyops* from the Mahadeo Series.

Reptiles. Reptilian life, like the plant life of the middle Gondwanas does not show the same diversity and abundance as that of the corresponding Triassic Period of America and Europe The only reptiles recorded from Panchet Series are *Dicynodon* and *Ptychosiagum* and the dinosaur, *Epicampodon* From the Maleri Series, crocodilean forms, *Belodon* and *Parasuchus*, and a giant lizard, *Hyperodapedon*, which are identical with those of the Triassic of Europe, have been discovered. It was probably due to the cold climate of Gondwanaland that reptiles, which are mostly warmth-loving animals, did not flourish to the same extent as in the Northern Continent.



Courtesy GSI, Calcutta

SOME TRIASSIC ANIMAL FOSSILS FROM INDIA AND NEIGHBOURING COUNTRIES

1, *Rhynchonella trinodosi* Bittn., 2, *Daonella lommeli* Wissm., 3 *Monotis salinaria* Schloth., 4, *Pseudomonotis griesbachi* Bittn., 5, *Celtites multiplicatus* Waag. 6 *Ceratites wynnei* Waag., 7, *Meekoceras koninckianum* Waag., 8 *Otoceras clivei* Dien. 9, *Ophiceras sakuntala* Dien., 10, *Sibirites prahlada* Dien., 11, *Ptychites cognatus* Oppel 12, *Xenodiscus himalayanus* Griesb. (1-2, Brachiopoda, 3-4, Lamellibranchiata, 5-12, Cephalopoda)

Fossil remains of crocodile-like reptiles have been recovered from the middle Triassic red beds of the Rocky Mountains of America Tracks of dinosaurs have been discovered in large numbers from sandstones of Connecticut valley. Some of the sandstones are covered with three-toed tracks of bipedal animals, which were first mistaken for bird tracks. The Triassic dinosaurs varied in size from a sheep to a horse Some were bipedal, walking on well developed hind legs, with forelegs reduced to a small size, dragging a heavy tail behind, and were agile jumpers like kangaroos The dinosaurs branched out into many types, large and small, slow and ponderous, active and agile, and vegetarians and beasts of prey.

Some land animals like ichthyosaurs re-invaded the sea, they are called "secondary aquatics". On account of land life which their ancestors led, they had stronger and more agile bodies, a tough and drought-resistant skin, greater power of self-regulation, and more efficient protection for young ones With these advantages, the "secondary aquatics" who had returned to the sea, beat the animals who had never left the ancestral waters Ichthyosaurs of the Triassic, however, had fewer teeth, normal five fingers in the flippers and less powerful tails as compared to their Jurassic successors

Theromorphs—the connecting link between reptiles and mammals. The most remarkable reptiles of the Triassic were *theromorphs*, or *mammal-shaped* reptiles The theromorphan reptiles included among others, *Pareiasaurus*, a slow moving creature with a clumsy appearance, and theriodonts or reptiles with mammal-like teeth, e g *Cynognathus* *Pareiasaurus*, which has been collected from the Karoos of South Africa, was vegetarian with pillar-like legs supporting the body, and was one of the earliest vertebrates to raise its belly off the ground Locomotion with belly lifted off the ground, was one of the major achievements of theromorphs as compared to creeping and wriggling movements of reptiles Another advance which the theromorphs show is the differentiation of the teeth into different groups, incisors, canines and molars, each with a characteristic shape and function, as in mammals

One of the major differences between reptiles and mammals is that in mammals the lower jaw consists of a single bone on either side, whereas in reptiles it consists of several bones joined together What happened to the extra bones of the lower jaw in the process of evolution from the reptilian to the mammalian lower jaw ? The bones of the middle ear in mammals, the 'hammer' and 'anvil', correspond to the two bones which in reptiles make the hinge-joint of the upper with the lower jaw. In the early development of mammals, these bones are actually nipped off from these very regions of the developing jaw This process is seen in an evolutionary sequence in theromorphs, while in the early forms the lower jaw resembles that of reptiles, in the intermediate forms we

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and estuarine and marine molluscs, including ammonites The outcrops near the town of Rajahmundri are composed of littoral sandstone, gravel and conglomerate with a few shale beds containing marine lamellibranchs and ammonites Intercalated with these are beds containing impressions of the leaves of cycads and conifers Another outcrop of the same rocks is found on the south of the Krishna, near the town of Ongole A third group of these rocks occurs near Madras, and a fourth on the Mahanadi delta at Cuttack The Jurassic sandstones of the Mahanadi have furnished material for many buildings and temples including the well-known temples of Konarak and Jagannath at Puri On weathering, the Gondwana rocks yield a sandy shallow soil of poor quality

In Rajasthan, the Jurassic rocks are largely concealed below the sands of the Thar desert and only a few patches are exposed in southern area and in Jaisalmer and Bikaner The Kutch Jurassic rocks are very rich in fossil cephalopods, many of which show a relationship with those of Malagasy (Madagascar)

Extensive marine and continental deposits occur in Europe and America Jurassic red beds with gypsum occur in the Colorado plateau Volcanoes were active in the early Jurassic from southern Alaska down to California On the whole, the Jurassic was a period of stability However, mountain building took place in North America—the Nevadan Revolution, which continued until the close of the Jurassic, and gave birth to the Sierra Nevada mountains

Palaeogeography

During the Jurassic, considerable changes took place in the configuration of the continents The Gondwanaland separated into two land masses, the western and the eastern Modern Africa and South America constituted the western land mass, whereas the eastern land mass comprised Madagascar, peninsular India, lower Burma, Malayan Peninsula, Indonesian Islands, New Guinea and Australia The Tethys Sea separating India from Angaraland had considerably receded (Fig 53) Large freshwater lakes existed in peninsular India connected with the drainage of the surrounding country. After regional uplift about this period, the drainage in the Godavari and Mahanadi valleys carried the waters of the lakes into the sea which existed over the region now called the Bay of Bengal.

Towards the late Jurassic, marine invasion affected a large part of Rajasthan and Kutch A marine transgression also occurred on the east coast of the peninsular India, which resulted in the upper Gondwana deposits of the east coast between Visakhapatnam and Thanjavur along the Coromandel coast

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see the detachment of the two hinge bones, which grow smaller and smaller, till we find them converted into ear ossicles

While the theromorphs had a number of mammalian characters, they retained many reptilian features, e g the pineal foramen, a small hole on the top of the head, below which the third eye has been transformed into the pineal gland

Advances in Animal Life

From the evolutionary viewpoint, the Triassic saw the extinction of some characteristic Palaeozoic life forms, such as the Tetracoralla type of corals, the straight-shelled nautiloids, the trilobites, the cystoids, the blastoids and the eurypterids The groups which continued from the Palaeozoic were represented by different genera, although a few Palaeozoic genera too passed over into the Triassic Several new groups emerged such as the lobsters, reptiles of various kinds, and the primitive mammals Corals and molluscs became abundant, but brachiopods and amphibians decreased considerably in species as well as in numbers The animal life was now dominated by the reptiles. The Triassic fauna also exhibits much more complexity of forms, as in the complex-chambered cephalopods and in other higher forms of animal life Besides these qualitative and quantitative changes in the animal life, modernization is exhibited by most animals, as in stone lilies, asterozoans, the pelecypods, gastropods, and cuttlefishes It is, however, interesting to note that some of the groups which made their first appearance during this period and later attained considerable development were the echinoids, crustaceans, and primitive mammals

Origin of mammals Theriodonts, which have been discovered from the Triassic rocks of South Africa, are synthetic types, combining the characters of reptiles and mammals It is possible that the mammals originated from some of the smaller theriodonts in the Permian The South African part of Gondwanaland is possibly the place of origin of mammals The glaciation of Gondwanaland in the Permian, coupled with aridity, provided a stimulus to bodily activity, and it is thus that warm-blooded primitive mammals arose from theriodont forms which were half reptiles and half mammals These theriodonts had already started walking with the body supported by feet, and increasing aridity provided the stimulus to speed and activity In a cold climate, heat retention was just as important as warm-bloodedness, and it is thus that the hairy coat of the mammals developed to provide protection against the cold of Gondwanaland According to Lull, Triassic was the culmination of the process of emergence of mammals, for apart from theriodonts, actual fossils of mammals have also been found These early mammals were small in size, not on the average exceeding the size of a rat The Allotheria or Multituberculata are

among the oldest mammals, and their skulls, and tuberculate molars and cusped premolars, have been discovered from South Africa, Europe and North America. Thus, we find that the great group of mammals which became prominent in the Eocene Period took its origin as early as Permian, and remained obscure throughout the Mesozoic, when giant reptiles were the lords and masters of the earth. The Mesozoic mammals were very small creatures as compared to those of the Cenozoic, suggesting that "the upwelling of *future organic rulers began in unobtrusive small forms*".

CHAPTER TWELVE

THE JURASSIC PERIOD

The Age of Dinosaurs, Pterodactyls, Primitive Birds and Cycads

THE ROCKS overlying the Triassic were first studied in England towards the close of the nineteenth century by William Smith who named them 'Oolitic' because of oolitic limestone in them. Later, they were named as 'Jurassic' after the Jura mountains, between France and Switzerland, where they are well exhibited and were extensively studied. The Jurassic Period ended about 110 million years ago and had a span of about 30 million years

The Jurassic rocks found in the Himalayas in India are marine. They comprise limestone and shales, considerably thick deposits of which are found in the Zanskar Range of Spiti and in Garhwal and Kumaon The Ktoto limestone is 600–900 m. thick, forming lofty, precipitous rocks facing the Punjab Himalayas The most characteristic Jurassic formation of the inner Himalayas is the splintery and micaceous Spiti shale, about 90–150 m thick. Clays and sandstones with lignitic seams, ranging in age from the middle Jurassic to upper Jurassic, are found in the Salt Range in Pakistan About 1000 tonnes of coal per year are worked out from Kalabagh Jurassic limestone rocks, called Morini, which are also met with in Baluchistan.

The Jurassic (upper Gondwana) rocks are found from Rajmahal hills in Bihar to the neighbourhood of Madras The outcrops of these rocks are seen in the Damodar, Mahanadi and Godavari valleys, and in the Satpura hills The Rajmahal hills are constituted principally of volcanic rocks attaining a thickness of 600 m. with intertrappean beds of sedimentary siliceous and carbonaceous clays and sandstones about 30 m. in thickness The flora of the Rajmahal Series is found in beds which are exposed at numerous places scattered over an area of nearly 10,000 sq km It was about half a century ago that Feistmantel described the fossil plants from Rajmahal hills, but the most exhaustive study of these plants has been made by B Sahni and his colleagues and students.

In the coastal regions of Coromandel and Kutch, the continental deposits are interstratified with marine rocks

In the outcrops along the Coromandel coast are seen fossil plants of Gondwana,

and estuarine and marine molluscs, including ammonites The outcrops near the town of Rajahmundri are composed of littoral sandstone, gravel and conglomerate with a few shale beds containing marine lamellibranchs and ammonites Intercalated with these are beds containing impressions of the leaves of cycads and conifers Another outcrop of the same rocks is found on the south of the Krishna, near the town of Ongole A third group of these rocks occurs near Madras, and a fourth on the Mahanadi delta at Cuttack The Jurassic sandstones of the Mahanadi have furnished material for many buildings and temples including the well-known temples of Konarak and Jagannath at Puri On weathering, the Gondwana rocks yield a sandy shallow soil of poor quality

In Rajasthan, the Jurassic rocks are largely concealed below the sands of the Thar desert and only a few patches are exposed in southern area and in Jaisalmer and Bikaner The Kutch Jurassic rocks are very rich in fossil cephalopods, many of which show a relationship with those of Malagasy (Madagascar)

Extensive marine and continental deposits occur in Europe and America Jurassic red beds with gypsum occur in the Colorado plateau Volcanoes were active in the early Jurassic from southern Alaska down to California On the whole, the Jurassic was a period of stability However, mountain building took place in North America—the Nevadan Revolution, which continued until the close of the Jurassic, and gave birth to the Sierra Nevada mountains

Palaeogeography

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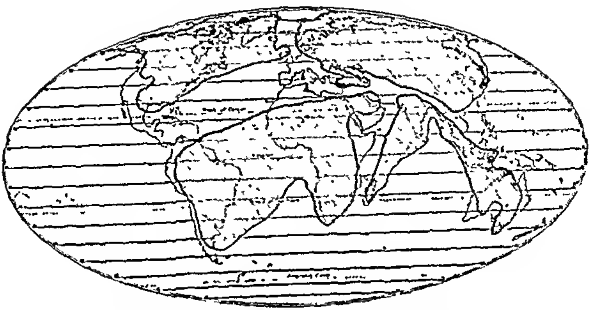


FIG. 53 MAP OF THE WORLD IN THE MIDDLE OF THE JURASSIC PERIOD. Land is shown by shaded areas (After Arldt)

sea advanced in the early Jurassic and spread eastward to eastern California. Another arm of the sea from the Gulf of Mexico advanced into Mexico and Texas, and later the Arctic Sea extended as far as central Colorado. These marine invasions in North America were short-lived and withdrew during the upper Jurassic. The uplift of the Sierra Nevada mountains in late Jurassic resulted in the withdrawal of the Pacific Sea.

Climate. The curbing or dwarfing of various marine and land animals and plants points to a somewhat cool climate during the early Jurassic, which became mild during the middle and late Jurassic. Corals were distributed much farther northwards than their present range, and the dinosaurs have been found as far north as Montana.

The Arctic Ocean was cooler than the Atlantic and the Pacific. Alaska and Graham Land, where arctic climate prevails today, were covered by luxuriant vegetation, suggesting a much milder humid climate. In the western interior of the United States, desert or semidesert conditions prevailed as indicated by the Red beds and great cross-bedded sandstone formations.

PLANT LIFE

Plant life during the Jurassic was far more luxuriant than in the Triassic and largely consisted of ferns, cycadophytes and conifers. *Fig. 54* shows a Jurassic landscape with

dominant plants and animals during the period. Fig. 55 shows the Jurassic plant life in the Rajmahal hills, Bihar, India.

One of the features of the Jurassic floras is their uniformity in widely separated regions of the earth. Describing the Jurassic flora of the Yorkshire coast, Seward writes, "Our first impression might be that we were in some tropical region. *Conifers of familiar habit dominated the forest; river banks hidden under a* tangled riot of luxuriant ferns; group of horsetails (*Equisetum*) spreading a green mist over flat stretches of land. We would be struck by the absence of broad-leaved trees festooned with rope like climbers and their branches lifting up to the sunlight clusters of humbler flowering plants. We might well think that we had wandered into a tract of country where for some reason the ground was

FIG 54 A JURASSIC LANDSCAPE. *Cycadeoidea* is on the right and *Williamsonia* and *Zamites* on the left. In the far background are conifers Resting on the rock and flying in the air are pterodactyls. Dinosaur-like creatures gliding are the ancestors of the birds. In the lagoon are the marine reptiles *Ichthyosaurus* and *Plesiosaurus*

FIG. 55 A JURASSIC LANDSCAPE OF RAJMAHAL HILLS, SHOWING IMPORTANT PLANTS OF THE PERIOD

monopolized by ferns, conifers and cycadophytes to the apparent exclusion of all flowering plants."

Lycopods

The lycopods were now exclusively herbaceous and were very much like the modern forms. Even in stem anatomy the resemblance is very close, as in the genus *Lycoxylon*.

Articulates

The genus *Equisetites* had become extremely common and cosmopolitan. Although some of the forms were still thicker than the modern *Equisetum* they were less thick than the Triassic forms. *Equisetites* was so much like *Equisetum*, that the Jurassic forms are now referred to the modern genus. *Phyllotheca*, *Neocalamites*, and *Schizoneura* were less common.

Ferns

One of the dominant groups of the plant kingdom during the Jurassic, the ferns exhibited considerable modernization in form and structure. In *Marattiopsis*, a close affinity

with some modern forms can be seen in the morphology of the leaflets and the structure of the sporangia The sterile and fertile fronds of *Cladophlebis denticulata* (the fertile ones are referred to *Todites denticulata*) are in no way much different from those of modern *Todea barbara* and the same may be said of the rhizomes of *Osmundites Matonidium* is close to *Matonia pectinata* and *Dictyophyllum* recalls the Indian and Malayan *Dipteris* and *Platycerium*

Cyatheaceae was represented by *Cyathocaulis* and *Cibotiocaulis*, and Gleicheniaceae by *Gleichenites* The modern genus *Gleichenia* closely resembles *Gleichenites* *G glauca* is found in the forests of Assam (Pl 46) Schizaeaceae was equally common and was represented by the genus *Klukia* All these possessed the essential characters of modern forms There were several other ferns represented by sterile fronds

Pteridosperms

The pteridosperms in the middle Jurassic were represented by *Thinnfeldia Dicroidium, Pachypteris, Cycadopteris, Lonchopteris*, and Caytoniales known from the Yorkshire coast

Caytoniales consist of foliage (*Sagenopteris*), microsporophylls (*Caytonanthus*) and fruit bearing stalks (*Caytonia*) (Fig 56) The leaves were compound—three to six, lanceolate leaflets, about 2–6 cm long, borne on a petiole—and had reticulate venation The megasporophylls were long dorsiventral structures and bore stalked fruits *in pairs* The round, sac-like fruits had a lip situated close to the stalk, which opened into the interior of the fruit Inside the fruit, small orthotropous ovules were arranged in a row on the curved inner surface The seeds, with the single integument free from nucellus to the base, were devoid of any micropylar beak. The microsporangiate organs bore short lateral branches on the central axis, which subdivided and bore four-chambered anthers Pollen grains were two-winged

Czekanowskia, originally referred to Ginkgoales, is another interesting plant which was widely distributed in the Jurassic. Its leaves, arranged in fascicles, about 15 on a short shoot, reached a length of 15 cm and were divided dichotomously into narrow and linear segments The associated seed bearing organs, *Leptostrobus*, consisted of a slender unbranched axis bearing appendages which were spirally arranged. Each appendage consisted of a pair of lobed valves, with three to five seeds borne on the inner surface of each

Pentoxylales

This interesting group of plants is known from India and New Zealand (Fig 57,1–4) The stem (*Pentoxylon*) was characterized by a ring of five, occasionally six, closely situated steles, each with tangentially elongated primary wood enclosed in strongly

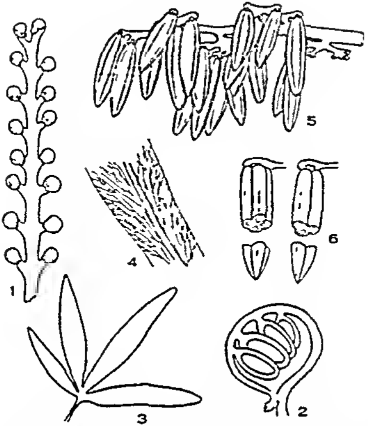
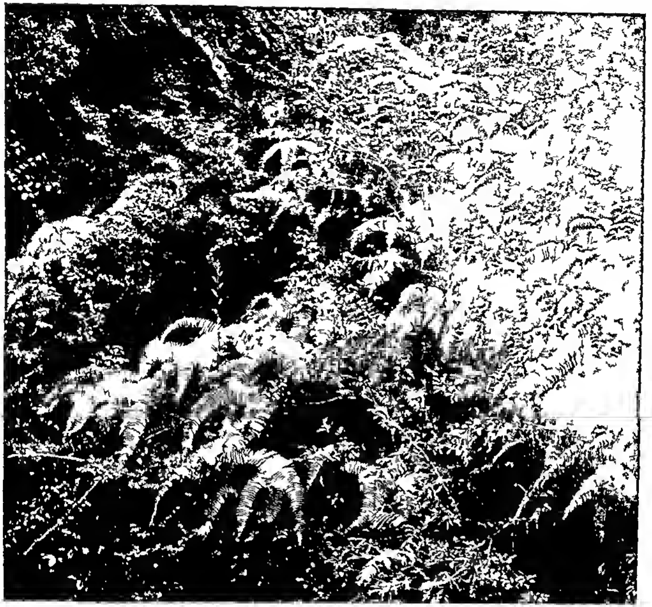


FIG. 56. THE CAYTONIALES (pteridosperms) FROM THE JURASSIC. 1 & 2, *Caytonia nathorsti* 1, Central axis bearing two rows of cupules; 2, A cupule or "fruit" in longitudinal section showing four seeds. 3 & 4, *Sagenopteris phillipsi* 3 A leaf with four leaflets, 4, A portion of a leaflet showing net venation. 5 & 6, *Caytonanthus kochi*, from East Greenland 5, Restoration of a portion of a microsporophyll, 6, Two anthers, one with four chambers and the other with three (1–4, after Thomas, 5–6, after Harris)

endocentric secondary wood. The stems in *Nipanioxylon* had more steles, with endocentric growth. The stems bore strap-shaped leaves. In *Nipaniophyllum raoi*, the leaves were upto 7 cm long and traversed by a midrib with parallel, lateral veins. The midrib consisted of a row of vascular bundles which resembled those of modern cycads. The stomata were also cycadean in character.

The seed bearing organs were borne in clusters on a peduncle which divided into several branches or pedicels, each terminating in a cone. The pedicels had 5 vascular bundles. The cone axis bore several closely compact seeds with thick fleshy integuments. The micropyle faced outwards. *Carnoconites compactum* had ovoid cones, and *C. laxum* elongate ones.

The male flowers, *Sahnia nipaniensis*, were borne on dwarf shoots and consisted of spirally arranged filiform appendages fused at the base to form a disc. Unilocular sporangia



Co y ICAR

THE FERN GLEICHENIA GLAUCA GROWING IN A FOREST IN ASSAM

It is a l ving fossil and closely rese nbles the fossil Gle chen tes

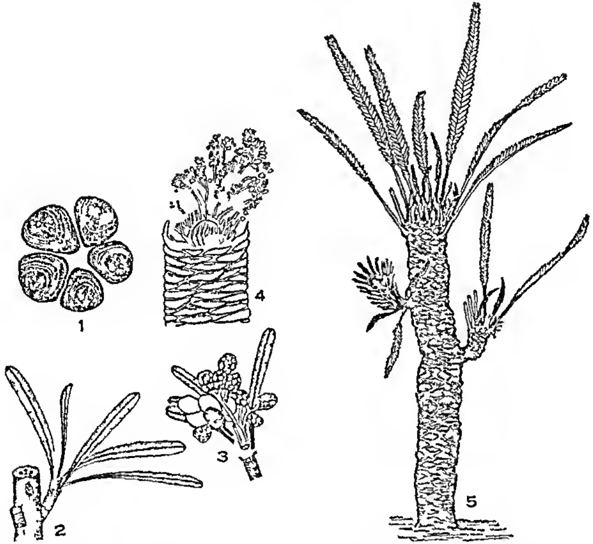


Fig. 57 1–4 The Pentoxyleae 1 Stelar system of stem (*Pentoxylon*) showing endocentric development of secondary wood 2, Foliage-bearing branch 3 *Pentoxylon sahnii* female cone 4 *Sahnia nipaniensis* male flower 5 A reconstruction of *Williamsonia sewardiana* from Rajmahal hills (1–3 after Sahni 4 after Vishnu Mittre 5 after Sahni)

were attached on short branches of these appendages Pollen grains were monocolpate and boat-shaped.

Cycadeoids

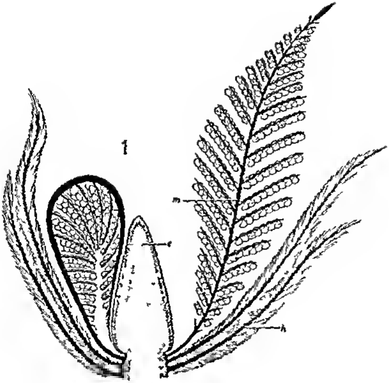
These were largely represented by the genera *Williamsoniella, Williamsonia, Cycadeoidea, Sahnioxylon* and several kinds of fronds such as *Pterophyllum, Dictyozamites, Ptilophyllum, Otozamites* and *Anomozamites.*

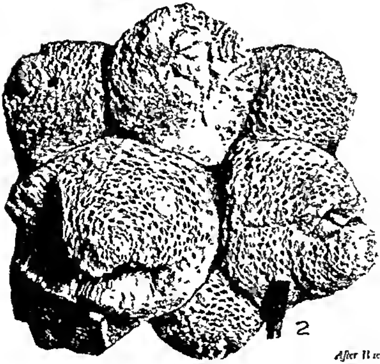
Williamsoniella coronata had slender, regularly forked stems and bore scattered leaves, *Nilssoniopteris vittata* The short-stalked flowers were borne on small fertile shoots in the forks of the stems. The flowers, probably axillary in nature, were bisexual Each consisted of a central column bearing the seeds and interseminal scales. The seeds were very small and as many as 300 have been found attached to 10 mm length of column Interspersed among them, there were 1200 interseminal scales, each made up of a slender stalk and a terminal bulbous head. The central column was surrounded by a ring of 12 to 14 separate microsporophylls attached at its base Each microsporophyll bore two pairs of capsules partially enclosed by finger-like branches The two-valved capsule was made up of several sporangia The microsporophylls were probably shed after spore dispersal and they have been found detached. A perianth of hairy bracts enclosed the whole structure.

The stems of Williamsonias, like those of modern cycads, were clothed with the bases of old leaves and bracts and bore palm-like leaves (Fig 57 5), but the flowers were different. The trunk, about 2 m. tall, had many cycadean characters in the nature of rays, and pitting and endarch protoxylem The flowers were unisexual The female flower consisted of a central receptacle covered with long stalked ovules and the club-shaped interseminal scales The male flower consisted of a cup-shaped structure with flaring lobes and with sporangia attached on their inner faces. In *Williamsonia spectabilis*, the lobes bore slender branches on which two rows of synangia were attached. The male flower was stalked in *W spectabilis*, but it was sessile in *W whitbiensis* which had the synangia directly attached on the *inner surface* of the lobes In *W santalensis*, the basal disc was *more* shallow and each lobe was divided into a blunt terminal portion and a narrower side which bore two rows of finger-like appendages, each including two rows of chambers

Cycadeoideas had short columnar trunks and bore an armour of leaf bases and multicellular hairs The flowers partially sunk in the leaf bases were borne laterally on the trunks Pl 47 2. A large pith was surrounded by a thin zone of wood. Protoxylem was endarch. The secondary xylem consisted of scalariform tracheids and uniseriate to biseriate rays Cortex was parenchymatous with gum canals and leaf traces. The leaf trace originated as a single strand and divided in the mesarch region into many strands arranged in a horseshoe-shaped curve It followed a direct course upward and did not show curvature around half of the circumference of the stem as in modern cycads. The leaves were like those of modern *Macrozamia*, *Encephalartos* and *Bowenia* Some of the Cycadeoideas were monocarpic, fruiting only once during their life time

The flowers were unisexual or bisexual borne on stout fertile shoots on which the pinnate bracts were arranged spirally The apex of the shoot terminated in the ovuliferous receptacle which was convex, as in *Cycadeoidea gibsonianas*, or elongate and nearly





After Wieland

1, CYCADEOIDEA DACOTENSIS, SEMIDIAGRAMMATIC SKETCH OF A FLOWER IN A LONGITUDINAL SECTION

h, hairy bract, m, expanded microsporophyll, c, central axis with numerous seeds and interseminal scales

2, STEM OF CYCADEOIDEA MARSHIANA

CYCAS REVOLUTA, A LIVING FOSSIL PLANT, WHICH HAS MOTILE SPERMS

The plant shown is female with woolly megasporophylls between the two layers of leaves. It has many characters of the Jurassic cycads

cone-shaped as in *C dacotensis* (Pl 47 1) and *C ingens* It was cushion-like and bore a cluster of stalked ovules and interseminal scales Ovules were erect with a long micropyle Seeds were small oval bodies The tips of the scales were enlarged and club-like, fitting into the spaces between the seeds and were fused to form a continuous layer with openings for the micropylar beaks

The receptacle was surrounded by a ring of microsporophylls fused below to form a disc The microsporophylls were pinnate organs and the middle pinnae bore two rows of synangia, whereas the basal and apical pinnae were sterile The synangium dehisced by a longitudinal slit and its wall was made up of palisade tissue

Cycads

The best known remains of this group are known from the mid-Jurassic of Yorkshire The leaves, *Nilssonia compta*, had strong rachis and lamina divided into truncate segments The female fructification *Beania gracilis*, consisted of a long axis bearing spirally arranged stalked appendages which had a distal expanded head with two seeds on the inner surface The seeds were large (up to 16 × 13 mm), with a two-layered integument the outer fibrous, enclosing the inner stony layer The male cones, *Androstrobus manis*, were 5 cm long and 2 cm in diameter Numerous spirally arranged sporophylls bore scores of cylindrical sporangia on the under surface Many characters of the Jurassic cycads may be seen in the modern genus *Cycas* *C revoluta* is a common garden plant in many parts of India (Pl 48)

Conifers

In the Jurassic plant life conifers formed another dominant group Several kinds of sterile shoots have been described some of which on the basis of morphology and anatomical characters have been referred to modern families *Elatocladus* *Sphenolepidium*, *Nageiopsis* etc to Podocarpaceae, *Brachyphyllum* and *Pagiophyllum* to Araucariaceae, *Elatides* and *Sciadopitys* to Taxodiaceae *Cephalotaxites* to Cephalotaxaceae, and *Pinites* and *Pityocladus* to Pinaceae Several of these are form genera and some of them show intermediate characters between cycadophytes and conifers e g *Podozamites* *Elatides* had foliage like *Araucaria excelsa* but the cones resembled those of *Picea* or *Abies*

The variety of foliage is substantiated by the occurrence of many kinds of fossil woods which are referred to several families and genera such as *Mesembrioxylon* (Podocarpaceae), *Araucarioxylon* and *Dadoxylon* (Araucariaceae), *Cedroxylon* and *Piceoxylon* (Pinaceae), *Taxodioxylon* (Taxodiaceae), and *Cupressinoxylon* (Cupressaceae)

Along with the foliage and woods both male and female fructifications have also been found Several species of *Masculostrobus*, with 2–3-winged pollen, are referred to

Podocarpaceae. Male cones on the *Brachyphyllum* shoots with unwinged pollen and female cones with ligulate single-seeded scales (*Araucarites bindrabunensis*) and detached single-seeded scales (*Araucarites*) are the fertile remains of Araucariaceae. Besides, dispersed pollen referable to Pinaceae, Araucariaceae and Podocarpaceae occur profusely in the Jurassic rocks. Male cones had almost the same organization as in modern conifers. The female cones too were not very different from their modern counterparts.

Several kinds of Jurassic seed-cones have recently been described from the Rajmahal Series of India. They are compact to loose with each seed-scale complex consisting of delicate, fleshy fertile scale and a recurved ovule with an epimatium, as in the genus *Nipaniruha*. In *Sitholeya* the shoot terminates in a single inverted ovule as in modern *Podocarpus*. The genus *Nipaniruha* is comparable to modern *Dacrydium*, *Pherosphaera* and *Microcachrys*. *Mehtaia* is more *Pherosphaera*-like. These cones from India exhibit successive steps in gradual recurvation of ovules and the appearance of epimatium as a result of it.

Both small and large seed-cones of Pinaceae have been found in the Jurassic. Of these, the elongate cones of *Pinites strobiliformis* resemble those of *Pinus strobus*. A broader and shorter cone is referred to *Pinus sarnegi* known from the upper Jurassic of France.

Elatides williamsonii known from the middle Jurassic of Yorkshire, is a distinct member of Taxodiaceae. The sessile male cones were borne in clusters at the tips of leafy twigs. The stalked stamens bore expanded diamond-shaped heads each bearing three elongated pollen sacs. The seed-cones were borne terminally. Each seed-scale complex consisted of a stout stalk and an expanded distal portion ending in a tapering apex. Five ovules arranged in an arched row were present at the junction of the stalk and the distal part.

Amongst the genera that extended from the upper Triassic to lower Jurassic may be mentioned *Schizolepis*, *Palissya*, *Stachyotaxus* and *Araucarites*.

In *Swedenbergia* both the sporophyll and the five inverted ovules were aggregated and the entire bract was free only in the apical region. The lower Jurassic *Cheirolepis* had axillary seed-scale complexes, made up of six sterile scales with two basal megasporophylls each with one inverted ovule at the apex. *Hirmerella* of the same age had what appears to be a single sterile scale and two megasporophylls with inverted ovules making a seed-scale complex.

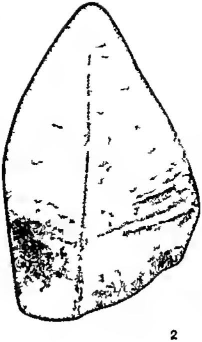
Taxads

These were represented by *Taxus jurassica* known in Yorkshire. It consisted of radially symmetrical dwarf shoots in the axils of small scale leaves each bearing one erect, slightly flattened, arillate ovule.

Angiosperms

The Jurassic plant life also included some forms which seem to show characters

1



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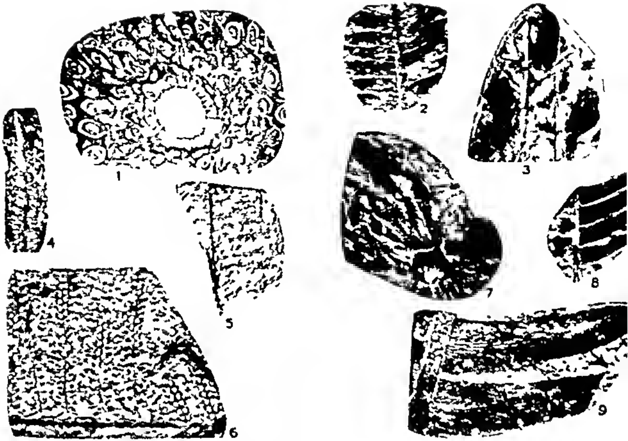
3

Ca r e y B lal Sal I e Pa a a y l kr o

SOME JURASSIC PLANT FOSSILS FROM INDIA

1 Pt l pl yll m a l ense McCl 2 Mara an iop er lata Oldl & Morr 3 M lus a n pan en \ l nu M rre



Courtesy Birbal Sahni Institute of Palaeobotany, Lucknow

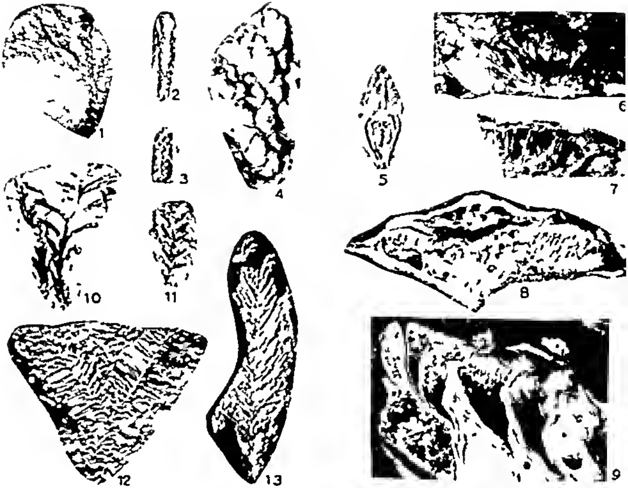
SOME JURASSIC PLANT FOSSILS FROM INDIA

1. *Osmundites sahnii* Vishnu-Mittre, cross-section of a rhizome. 2. *Dictyozamites indicus* Feist. 3. *Nilssonia princeps* Oldham & Morris. 4. *Marattiopsis macrocarpa* Oldham & Morris. 5 & 6. *Gleichenites gleichenoides* Oldham & Morris, fertile specimens. 7. *Williamsonia santalensis* Sitholey & Bose. 8 & 9. *Dictyozamites falcatus* Morris.

Courtesy Birbal Sahni Institute of Palaeobotany, Lucknow

SOME JURASSIC PLANT FOSSILS FROM INDIA

1, *Sitholeya rajmahalense* Vishnu Mittre 2, *Mehtaia santalensis* Vishnu Mittre 3 *Masculostrobus polycarpoides* Vishnu Mittre 4 9 & 10 *Carnoconites laxum* Srivastava 4 an impression 9 a cone shown enlarged 10 a part of infructescence with three cones, 5 *Nipaniophyllum raoi* Sahni 6 a part of infructescence of *Carnoconites compactum* Srivastava in vertical section 7, Male cone of *Nipanioruha granthia* Rao emend Vishnu Mittre 8 *Masculostrobus sahnii* Vishnu Mittre



Courtesy Birbal Sahni Institute of Palaeobotany, Lucknow

SOME JURASSIC PLANT FOSSILS FROM INDIA

1-4 *Brachyphyllum mammillare* Feist. 4 enlarged. 5 *Araucaria cutchensis* Feist. 6-9 *Araucarites bindrabunensis* Vishnu-Mittre. 7 cross-section of a part of cone axis. 8 cross-section of a fertile scale showing ovule attached to the sterile scale. 9 a vertical section of some fertile scales showing ovule. 10 *Elatocladus* sp. 11 *Taxophyllum* sp. 12 *Elatocladus tenerrima* Feist. 13 *Elatocladus plana* Feist.

of angiosperms Amongst the leaves, *Phyllites* from Yorkshire, is comparable with *Cercidiphyllum* *Sassendorfites benkeri*, from Sassendorf near Bomberg, looks like a dicot leaf A palm *Propalmophyllum liasinum*, from France, may also be mentioned

Some of the Jurassic plant fossils from India are shown in Pl 49 to 52

Advances in Plant Life

A review of the Jurassic fossils reveals a more modern flora As Seward observes, "Moribund survivors from the Palaeozoic world disappear and more modern and familiar types become increasingly abundant, we get into closer touch with lines of evolution leading directly to genera and species which are still with us". Archaic forms like the Cordaitales, arborescent lycopods, and most of the pteridosperms had disappeared The Equisetales had dwindled into insignificance Ferns, many of which can be assigned to modern families, had become widespread. Conifers, many of which look familiar, had become dominant forest trees Cycads were widely distributed and dominated the flora Angiosperms probably arose from forms like Caytoniales and Bennettitales, but played only a humble part in the Jurassic flora

An important aspect of evolution of plant life during the Jurassic was further reduction of the plant groups, some of which were of wider distribution during the Palaeozoic *Phyllotheca*, *Neocalamites*, *Schizoneura* and *Equisetites* were the sole survivors of the Palaeozoic articulates, Lepidodendrons became extinct, but *Lycopodites* and *Selaginellites* continued to exist, among ferns, there was hardly any Palaeozoic remnant, descendants of pteridosperms were represented by Caytoniales Jurassic plant life also exhibits progressive modernization, an evolutionary trend commencing in the Triassic Species of *Equisetites* are almost like those of modern *Equisetum* Close similarities can be observed among Jurassic and modern lycopods, members of Marattiaceae, Osmundaceae, Schizaeaceae and other ferns, some conifers (*Araucarites* and *Pinites*) and cycads (*Androstrobus*)

Sudden decline of the Palaeozoic representatives and progressive closeness with the modern flora were accompanied by quite a few new kinds of plant life such as Pentoxylales The Bennettitales, which emerged in the Triassic, became varied and dominant in the Jurassic Although very much different in the nature of their fructifications, they possessed several characters of habit, foliage, and stems which recall those of modern cycads, despite the striking differences in cuticular structure The enfolded fronds of *Cycadeoidea ingens* are like those of *Encephalartos*, *Macrozamia* and *Bowenia* among the modern cycads, and short, branched stems are not different from those of modern *Zamia* But for the direct course of leaf traces and absence of medullary bundles, the anatomy of the wood is very much like that of modern cycads, and the seed structure is also closely allied. The differences

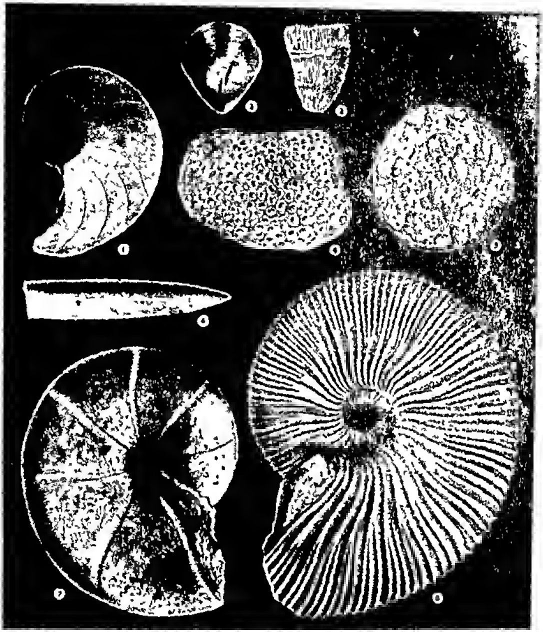
in stomatal apparatus and the organization of fructification keep them apart from modern cycads. True cycads had already existed along with the Bennettitales not only in the Jurassic but even in the Triassic. It will indeed be too far fetched to think that the Bennettitales are the precursors of modern cycads. Their origin from common ancestors may be a plausible possibility but any such common ancestor is difficult to imagine New kind of stomatal structure and strange looking fructifications caution us against seeking their ancestry in the pteridosperms

On the whole, evolutionary trends acquired during the commencement of Mesozoic are more fully expressed during the Jurassic. Jurassic conifers however, reveal some of the evolutionary trends carried over from the Palaeozoic, such as the aggregation of the fertile and sterile scales and the bracts in *Swedenbergia* and further reduction in their number in *Hirmeriella* which has a single sterile scale and only two megasporophylls The evolution of conifers as witnessed in the preceding geological periods links *Lebachia* or *Walchiostrobus* with the modern forms through disappearance of dichotomy of the bract scale and reduction and aggregation of both sterile and fertile scales The newly discovered podocarps from the Jurassic of the Rajmahal hills are perhaps the descendants of the line of evolution headed by *Ernestiodendron*, which lacked sterile scales The seduction of several fertile scales to one followed by the recurvation of the ovule and the appearance of epimatium as a result of it, may perhaps comprise possible steps through which seed scale complexes of *Nipamoritha* have originated and evolved into loose and compact seed-cones These steps continued further and gave rise to few- to single-seeded fructifications in modern podocarps Some Jurassic podocarps, *Sitholeya* for instance, indicate this

Further strides in the evolution of angiosperms are seen in the emergence of bisexualism in the bennettitalean flowers and the arrangement of the essential organs on the axis as seen in *Ranunculus*, in the fruits of *Caytonia* with enclosed seeds in palm-like leaves wood showing homoxyly, the net-veined leaves of *Sagenopteris*, and in the pollen possessing characters hitherto unknown in any other group of plants, except angiosperms. It may be too far fetched an idea to look upon the Pentoxylales as immediate ancestors of modern Pandanaceae, as held by some At the same time, the above evidences of angiospermy in the Jurassic can hardly be underestimated or overlooked.

ANIMAL LIFE

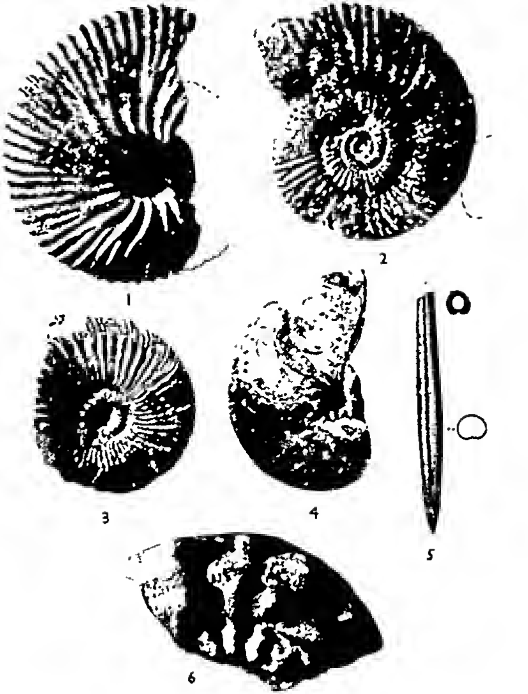
The Jurassic animal life was almost the extension of the Triassic with qualitative and quantitative changes in some groups and the emergence of some new ones exhibiting increased modernization in all aspects Some of the Jurassic animal fossils from India and neighbouring countries are shown in Pl 53



Courtesy GSI, Calcutta

SOME JURASSIC ANIMAL FOSSILS FROM INDIA AND NEIGHBOURING COUNTRIES

1, *Nautilus kumaguensis* Waag from north of Kumaguna, Kutch, 2, *Holcothyris subovalis* Buckman from Man Hslan, Northern Shan States, Burma, 3, *Montlivaltia cornutiformis* var *crassa* Gregory from north west of Jumara Kutch 4, *Stylina kachensis* Gregory from north-west of Jumara, Kutch, 5, *Isastraea hemisphaerica* Gregory from north-west of Jumara, Kutch, 6 *Belemnites katrolensis* Waag from Kutch, 7, *Phylloceras disputabile* Zittel from Keera hill near Chari Kutch, 8, *Stephanoceras sulcompressum* Waag from north-west of Soorka, Kutch (1, 6, 7 & 8 cephalopods, 2, brachiopods, 3, 4 & 5, corals)



Courtesy GSI, Calcutta

SOME TYPICAL CEPHALOPOD FOSSILS FROM THE JURASSIC OF INDIA AND THE NEIGHBOURING COUNTRIES

1. *Indosphinctes* [illegible] (Waag.) 2. *Torquatisphinctes torquatus* (Sow.) 3. *Subkossmatia* [illegible] (Sow.), 4. *Perisphinctes* cf. [illegible] (Waag.) 5. *Belemnopsis gerardiana* (d'Orb) 6. [illegible] *kachhense* Spath

Invertebrates

The foraminifers, the radiolarians and the sponges became very abundant and diversified. Corals were also very common but they were all of the hexacoralla-type and of modern appearance Like the modern forms they were tiny individuals secreting carbonate of lime from sea water and growing into profusely branching colonies The crinoids were very profuse and notably large and complex. The single individuals in some of the Jurassic forms had more than 600,000 segments made up of carbonate of lime Asterozoans continued to maintain their Triassic status Echinoids attained prominence and variety During the early Jurassic, only the regular and radially symmetrical forms existed, but later in the period the irregular and bilaterally symmetrical forms made their first appearance showing progressive evolution towards the modern forms Bryozoans continued to be present, but brachiopods were further reduced A gradual increase of shells with curved hinge-lines over those with straight hinge-lines marked a further change in the brachiopods

The pelecypods and the gastropods continued as in the Triassic and were more abundant They were very varied and included several modern genera *Exogyra* and *Gryphea* were common during the Jurassic and Cretaceous Cephalopods reached their zenith of development during the Jurassic (Pl 54) The compartment partitions in the coiled forms became highly complicated. Besides being complex, many of them were of large size Some of the coils were so large in diameter that if stretched out they would be 9 to 12 m long The ammonites adopted strange forms, some had uncoiled shells, others were spiral and curved, or straight. In some, the shells were highly ornamental The dibranchs became exceedingly abundant, both in number of species and individuals The highest beds of Kioto limestones in Spiti contain a rich assemblage of lamellibranchs and belemnites From the preponderance of the species *Belemnites sulcacutus*, they are called Sulcacutus beds From Spiti shales, a large number of genera of ammonites have been collected. A few of these are *Phylloceras, Oppelia, Aspidoceros, Hoplites* and *Macrocephalites* The lamellibranchs are represented by numerous genera, the commonest of which are *Avicula, Aucella, Lima, Pecten, Nucula, Leda, Arca* and *Trigonia* The gastropod species which have been collected belong to genera *Pleurotomaria* and *Cerithium* A large number of fossil cephalopods have been collected from Jurassic rocks of Kutch, which closely resemble those of Malagasy. A feature of the ammonites is their complex septa, and highly ornamental shells The belemnites were very much like modern cuttlefishes Some Jurassic forms were over 60 cm long In some, ink-sacs have also been found, as in modern forms

The lobsters, the decapods, which originated in the Triassic were represented by several genera and species in the Jurassic Besides the long-tailed lobsters, there were also short-tailed forms There were many intermediate forms between the long-tailed and the short-tailed forms

Insects in the Jurassic fauna were represented by hundreds of species Grasshoppers and cockroaches existed in the Jurassic Beetles amongst the higher forms were very abundant, but the other higher forms such as flies, bees, ants, butterflies and moths had only just appeared On the whole, the insect life was remarkably modern during this period

Vertebrates

The population of amphibians declined still further, but they were large in size

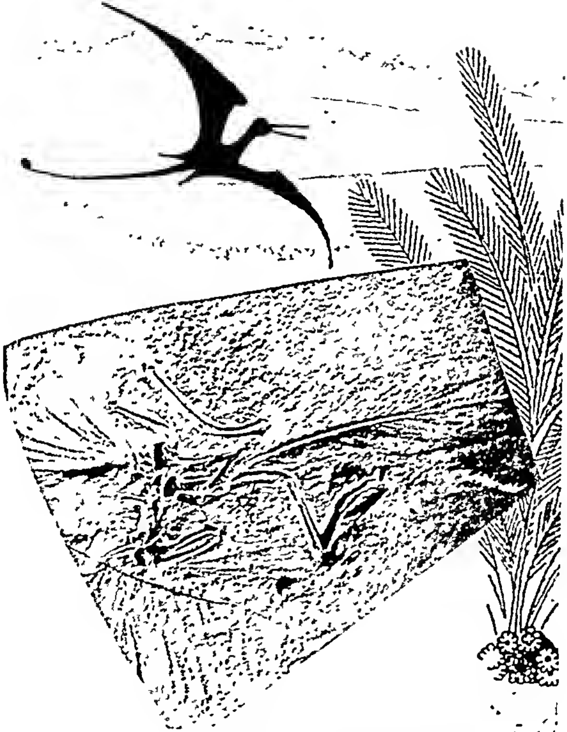
Amongst the fishes, the selachians and ganoids were common and dipnoans had become rare The teleosts, the true bony fishes, though rare, made their first appearance during the Jurassic. This group of the most highly organized of all fishes included such modern forms as salmon, cod and herring They were simple forms and on the border between the true ganoids and the teleosts

Reptiles were much like those of Triassic, but more varied. Besides the ichthyosaurs and plesiosaurs (Pl 55), there were true sea-serpents, the mosasaurs, carnivorous marine reptiles which were 12–22 m long In structure, they were much like snakes and lizards. The four limbs were modified into short, stout, swimming paddles and their jaws were studded with sharp teeth Their body was long and slender with a small head and a tail The ichthyosaurs increased in numbers in the Jurassic Because of their large size, greater strength and agility, they are believed to be the secondary aquatics since they re-entered water after a successful adaptation on land. These secondary aquatics, armed with many advantages, which the land-life had bestowed upon them, such as greater strength and agility, became monarchs of the seas and rivers Ichthyosaurs were torpedo-like in shape, and had close rows of small sharp teeth. Their limbs had become converted into paddles, and they swam with the aid of their powerful vertical tail-fins. The nostrils were on the top of the head, and this part of the body broke the water surface first, and facilitated air-breathing There was a parietal foramen on the top of the head It possibly lodged a pineal eye which functioned in addition to the two huge lateral eyes They were voracious carnivorous animals, and fish formed their main diet Some of them were over 12 m in length They did not lay their eggs on land, but were viviparous and gave birth to their young ones This is proved by the presence of skeletons of a litter within the ribs of a female ichthyosaur

Pa t g Cl a les R Kn gl t Co tesy Cl cago Na ral H ory M se

A SCENE OFF THE COAST OF N AMERICA IN JURASSIC TIMES ABOUT 130 000 000 YEARS AGO

Two types of the marine rept les are shown Plesiosaurs with long necks broad flat bodies and sturdy paddle shaped limbs and ichthyosaurs with fish like fins and tails Both types were fish eaters



After the original from the American Museum of Natural History, New York

FOSSIL OF ARCHAEOPTERYX DISCOVERED FROM SOLENHOFEN IN BAVARIA, AND ITS RECONSTRUCTION

Apart from ichthyosaurs and plesiosaurs, crocodiles, turtles, and tortoises had also adapted themselves to aquatic life, and many of them became marine *Metriorhynchus* was a sea-crocodile of the upper Jurassic Period, with a tail-fin like that of an ichthyosaur, and paddle-like limbs It was so well adapted to life in water, that it would never have come on land.

It was in 1878 that Marsh and Cope discovered dinosaur remains in Colorado, Wyoming and Utah, in the United States of America From the abundance of fossil bones it appears that North America had a fairly large dinosaur population One of the best known dinosaur quarry is near Vernal, Utah, where a national park known as 'Dinosaur Park' has been established. In this park, remains of many animals have been exposed in the rocks and have been left *in situ* for the benefit of sight-seers Dinosaurs were world-wide in distribution, and apart from USA, their remains have been found in Brazil, Patagonia, England, Belgium France, Germany, Austria, South Africa, India, Central Mongolia and Australia

Some of the dinosaurs were the largest land animals that ever lived, and reached a height of 21–30 m *Brontosaurus* was one of such giant dinosaurs It had a long neck and a tail, had pillar-like legs with solid bones, a huge body and small snake-like head. It was a sluggish vegetarian and possibly lived half submerged in water It was an egg-laying dinosaur, and its eggs, each of which equalled 100 hen's eggs in diameter, were hatched by the heat of the sun It was about 20 m long and weighed about 38 tonnes It was quadrupedal, though when buoyed up in water, it could walk on its hind legs

Stegosaurus was another formidable dinosaur, with a double fringe of huge triangular bony plates on its back Some of the largest plates were too heavy for one man to lift. The end of its tail was armed with fearful spines, which were powerful defensive weapons It had a hunch-backed appearance due to its very short front legs, and long and straight hind legs It had a very small head and a very small brain, weighing only about 300 grams, as compared to its body weight of 13 5 tonnes Such a small quantity of nervous matter could not control such a mass of flesh, and necessity arose for the development of a secondary brain in the vertebral column One of the vertebrae on the back was enormously enlarged and contained a large amount of nerve tissue which functioned as a secondary brain, and was the seat of the reflex and co-ordinating control of the large hind limbs and tail muscles *Diplodocus*, which has been collected from Wyoming was 26 m long, but its neck and tail were comparatively slender Its tail end acted like a whiplash, and was an efficient weapon of defence.

Many species of Jurassic dinosaurs have been described from almost all parts of the world. They range in length from 60 cm to 36 m *Compsognathus* was only about 75 cm in length, whereas *Gigantosaurus* from East Africa was about 36 m long and

weighed about 40 tonnes Some were vegetarians, whereas others were flesh-eaters. Some of them were kangaroo-like in appearance and ran on their hind legs and others were clumsy waders The sauropod dinosaurs were evidently senile forms, which specialized in bulk and were like moving mountains of flesh. While their carnivorous members persisted, most of their bulky representatives, as Lull states ' were released from the excessive burden of the flesh and suffered racial death in Cretaceous time, some millions of years before the passing of the dinosaurian dynasty In the Jurassic, however, they were stars in the great drama of mediaeval life, and compared to them, other terrestrial animals formed only a supporting cast."

Advances in Animal Life

The conquest of air. One of the major achievements of animal life in the Jurassic was the conquest of the air Air is about 800 times lighter than animal matter, and there was need of special modifications of body structure to overcome such a tenuous medium Pterodactyls, or the flying reptiles whose first recorded appearance is in the rocks of the uppermost Triassic Period, were the pioneers in this adventure These flying dragons, which looked like huge bats, became dominant in the Jurassic, and became extinct in the upper Cretaceous due to racial old age or increasing cold The pterodactyls were the most perfect flying vertebrates and had evolved many special adaptations for an aerial environment. Their bones were hollow, and instead of marrow were filled with air Hollow and light bones were an advantage in flying Their cerebellum was large and well developed as in birds and gave them power of quick adjustment of balance in an aerial environment Their eyes were also bird like In the pterodactyl wing, which was a patagium stretching between the forearm and the leg the fifth finger was greatly prolonged to support the wing on the top of which were three claw-like fingers In *Dimorphodon*, the humerus was perforated by a hole that permitted communication between the respiratory organs and the cavity of the bone In some forms even teeth were lost and bird-like beaks were developed.

The pterodactyls varied in size from a sparrow to an eagle *Rhamphorhynchus* was a flying reptile having a very long tail with a diamond-shaped end. The Cretaceous *Pteranodon* had a wing span of 8 m , and was the biggest flying animal ever known (Fig 54) However, its body weight did not exceed 14 kg In flying vertebrates a limit in size is reached sooner than in land mammals. In a heavier than air flying machine, the bigger a machine is, the faster must it fly to keep the body from crashing In flying vertebrates, the optimum weight is reached at about 23 kg Hence we find that in the pterodactyls the body was comparatively a small appendage to a huge pair of wings.

Like albatrosses the pterodactyls were probably fishers Perhaps they clung to rocks

near the sea-side with the aid of their claw-like vestigial fingers Most of the pterodactyl fossils have been collected from Solenhofen beds in Bavaria, which are marine deposits This is an indication that they flew over the sea, and sometimes got drowned and thus got preserved as fossils Their failure to evolve a covering of fur or feathers led to their doom With increasing cold in the Cretaceous, they perished in large numbers and ultimately became extinct

Origin of birds. The rise of the birds from reptiles was a major step in animal evolution in the Jurassic Birds possess many reptilian characters, and that is why Huxley called them 'glorified reptiles' The glory of a bird mainly lies in its feathers, and stripped of its feathers, it is quite lizard-like in appearance The Jurassic ancestor of the birds, *Archaeopteryx*, which has been discovered from a slate quarry at Solenhofen in Bavaria shows so many reptilian features, that it appears like a lizard on its way to becoming a bird (Pl 56) A specimen of this ancient creature which also bears the head is named *Archaeornis*, and was of the size of a crow. It had teeth in its jaws, possessed a long tail with vertebrae and having feathers on either side, a fully developed sternum, and three-clawed fingers of the hand projecting from the wing In the Jurassic birds, the vertebrae were biconcave, as in reptiles

According to Nopcsa, birds arose from bipedal running dinosaurs, who gathered speed by beating the air with their forearms Nopcsa's hypothetical bird ancestor *Pro-avis* was possibly a small dinosaur Discovery of small dinosaurs, like *Compsognathus*, which was hardly 75 cm long, from Solenhofen, supports the cursorial origin of birds The bones of these small dinosaurs were hollow, light, and bird-like The forearms became more effective as a parachute by the broadening of their surface due to the development of feathers, as a result of fraying out of the scales On account of increased activity, the bird ancestors became warm-blooded, and feathers, which are modified scales of reptiles, served a dual function, flight as well as conservation of heat. The covering of feathers was a major advance shown by birds over reptiles, and helped them to maintain a higher temperature, and ultimately to increase their physical and mental activity. This was particularly beneficial in the cold of the Cretaceous, when their naked competitors, the pterodactyls, perished on account of freezing cold, while the birds multiplied and spread all over the face of the earth.

A rival theory postulates an arboreal origin of birds According to this theory, the *Pro-avis*, the missing link between reptiles and *Archaeopteryx*, was an arboreal creature, which leaped from tree to tree Such creatures later developed into bipedal forms, and thus freed their forelimbs, which expanded and became wing-like and were of help in climbing trees Thus, they took to springing combined with flapping movements

of wings, and became permanently bipedal. From this transition the *Archaeopteryx* stage is easy, and these creatures mastered flapping flight combined with gliding, and permanent bipedalism. In this respect, the birds have great advantage over parachutists, like pterodactyls, in which the arm and leg were joined together by the patagium, while in the birds the leg is free to be used as such. Thus, the birds can both fly in the air and walk on the ground, while the parachutists could only fly or hang from rocks and trees in an inverted position. It is strange that the tree proved to be the salvation of the birds as well as of man, for bipedalism in ancestors of man is also believed to have developed because they climbed trees and thus freed their hands.

The Jurassic fauna, on the whole, was not much different from that of Triassic except for the abundant increase in several groups of animals, such as the foraminifers, the radiolarians, the crinoids, the echinoids, the pelecypods, the gastropods, the cephalopods, the decapods and the reptiles, and decrease in the brachiopods and the amphibians. The fauna exhibits a considerable progressive evolution towards modern form. Corals, exclusively of the hexacoralla type, irregular forms of echinoids, and the development of the curved hinge-lines on the shells of brachiopods are some outstanding examples. Several modern genera were evolved out of pelecypods and gastropods. *Belemnites* was very much like the modern cuttlefish. The crab family evolved. The tailed specimens of *Eryma* the like of which are found in the larval stages of modern crabs but not in the adult crabs, provide an excellent example of the Law of Recapitulation.

The evolution of variously ornamented and strange forms of ammonites is indeed spectacular. The Jurassic forms had developed a complicated suture or partition structure. The curved and the straight forms (*Baculites*) show a reversion to the early Palaeozoic forms.

From the simpler forms of insects in the Triassic to more diversified and higher forms in the Jurassic is an important step in the evolution of animal life. The insect life comprising bees, ants and butterflies was remarkably modern in aspect.

A great stride was made in the evolution of true bony fishes, the teleosts, during this period from ganoid fishes. The Jurassic forms were simpler and mostly on the border between true ganoids and true teleosts.

The reptiles were more common and varied. The ichthyosaurs increased. Several new groups of dinosaurs, such as mosasaurs, sauropods, stegosaurs and ornithopods were evolved. In these enormously huge creatures, brain was amazingly small. Modern elephant, which is big too, has a brain weighing about 3.6 kg, but the Jurassic reptiles much larger than the elephant, had a brain less than 90 g in weight. Crocodiles, resembling the modern gavial of India, originated during the Jurassic. In addition to the egg laying mammals, the monotremes, the origin of archaic marsupials during the Jurassic is another important step in the evolution of animals.

CHAPTER THIRTEEN

THE CRETACEOUS PERIOD

Age of Armoured Dinosaurs, Birds, Mammals, and Primitive Angiosperms

THE NAME Cretaceous is derived from the latin word *creta* meaning 'chalk', a characteristic rock-type, particularly of England, France and Germany in Europe, the Gulf Coast of North America, and Western Australia Chalk is a white, soft, fine-grained rock, essentially composed of calcareous shells and skeletons of minute organisms The abundance of microscopic foraminifers, like *Globigerina, Miliolites*, etc in the chalk led the earlier geologists to think that it was a deep sea deposit similar to the present day Globigerina mud found in the deep sea bottom Fragments of the skeletons of coastal organisms present in the chalk, however, indicate that it was deposited in calm seas no more than a few hundred metres deep The Cretaceous Period began some 110 million years ago and lasted for 50 million years

The Cretaceous system is represented by a varied assemblage of marine, fluviatile, and volcanic rocks, both in the extra-peninsular and peninsular regions of India The rocks, mostly comprising sandstones, limestones and shales occur in Spiti, Kashmir, Hazara and Kumaon Similar rocks also occur in Afghanistan, Persia and central Tibet Volcanic tuffs and breccia are found in the north-west Himalayas, Kumaon Himalayas Baluchistan and Burma, suggesting volcanic activity during this period. Besides, laminated ash beds, agglomerates and conglomerates, and bedded basaltic lava flows associated with limestone occur in Astor, Burzil and Dras in the north of Kashmir Thick deposits of Cretaceous sandstones occur in the Shillong plateau, comprising the Garo, Khasi and Jaintia hills In western India, massive red and brown sandstones with shales occur in Idar, Baroda, and Barmer A heterogenous composition including cherts, limestones, sandstones and shales also occurs from Gwalior to Kathiawar In Sind and Baluchistan, the upper Cretaceous can be made out from the lower by a small unconformity. Cretaceous rocks also occur in Burma and Andamans.

In South India, the Cretaceous rocks comprising limestones, gritty sandstones, clays and gravel beds occur in Ariyalur, Tiruchirapalli and Utatur Underlying the Deccan traps the Cretaceous deposits occur in central India and Deccan.

Palaeogeography

During the early part of Cretaceous Period, the Tethys extended over wide areas It spread over a great part of Europe. The southward extension of the Tethys flooded much of North Africa with a series of embayments from Algeria to Egypt. A connection was established with the South Atlantic Ocean across the Gulf of Guinea through Algeria, Libya, Sudan and Nigeria, converting the Sahara into a great island. In the eastern region, an arm of the Tethys spread over Iran, West Pakistan, western India, and lower parts of the Narmada and Tapti valleys, another arm invaded Assam, while embayments spreading northward from the Bay of Bengal merged with the arm of the Tethys in Assam The sea at this time washed the east coast of India where the upper Gondwana deposits are locally associated with marine fauna of lower Cretaceous age. The middle and upper Cretaceous, especially in the Pondicherry–Tiruchirapalli sector, are mainly littoral The fauna of this sector is similar to that of Malagasy (Madagascar) and South Africa and to that of the southern flank of the Assam range Along the Narmada valley on the west coast are some marine fossiliferous beds with fossils showing greater affinity with those of the Cretaceous of southern Arabia and Europe than with those of Assam and Tiruchirapalli regions The dissimilarity indicates that there was still a sort of land barrier that separated the Bay of Bengal from the Arabian Sea This land barrier has been called Lemuria which included India and Malagasy The sea surrounding this long Indo-Malagasy island, with its dinosaur infested forests, was in free communication with the Tethys to the north, as is shown by the presence of European species, or species with European relationships, in both the Narmada valley and the Cretaceous of the east coast of India The existence of Lemuria during the Cretaceous Period, as the remnant of the Eastern land mass of the Jurassic is, however disputed by many geologists

The middle and upper Cretaceous were periods of great marine transgression Fig 58 shows a map of the world about this time and Fig 59, a palaeogeographic map of Gondwanaland during the middle and upper Cretaceous

While the uppermost Cretaceous beds were being deposited along the south-eastern coast of India, stupendous volcanic outbursts overwhelmed a vast area particularly Gujarat Maharashtra and Madhya Pradesh the like of which is not known anywhere else in the world. Several hundred thousand square kilometres were flooded by quiet outpourings of extremely mobile lava from fissures that no longer exist (Fig 60) The hills formed by them are in some places over 1200 m high and are known as the Deccan traps They are peculiar in appearance, being frequently flat on the top and with steep sides so that they appear from a distance as gigantic steps and, therefore, called traps (Pl 57) a name derived from the Swedish word, meaning a stair or step The individual lava flows

DECCAN TRAPS IN THE WESTERN GHATS NEAR POONA

These mountains were built out of lava poured out at the close of the Cretaceous Period by numerous volcanoes

FIG. 58 MAP OF THE WORLD ABOUT THE MIDDLE OF THE CRETACEOUS PERIOD. The shaded areas are land This was a period of great marine transgression (After Arldt)

that make up the Deccan trap plateau vary greatly from a fraction of a metre to 36 metres in thickness During the periods of quiescence that intervened between successive outbursts, lakes were formed, probably because the lava streams had blocked the rivers. In these lakes, fishes, frogs, small crustaceans, etc flourished, while flowering plants including palms and other vegetation grew on the adjoining land In the marshy areas, dinosaurs thrived, and on the beaches, tortoises crawled As time went on, the lakes were filled up with sediments, washed down from the land Then came another period of volcanic outbursts and lava flows when lakes were formed again, and plants and animals reappeared Thus, volcanism and sedimentation were repeated many times until a great thickness of lavas and interbedded sediments, called the Intertrappeans, had accumulated containing the petrified remains of organisms which bear witness to the fauna and flora that existed during the period The most common shell of the intertrappean beds is *Physa prinsepii*, a species of freshwater snails In some places, aquatic plants including *Chara*, other freshwater algae, and *Azolla*, have been found.

Marine transgressions also characterized the Cretaceous Period in North America From the beginning, the sea started invading from the Arctic Ocean in the north and from the Gulf of Mexico in the south, across western Canada, Rocky Mountains area and the Great Plains, until the two inlets united in late Cretaceous time establishing a continuous

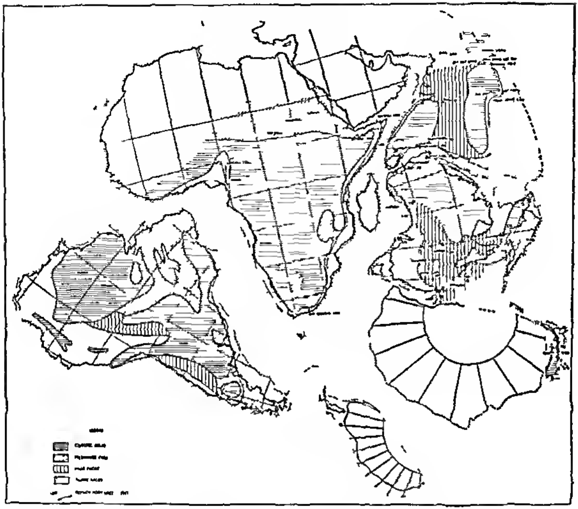


Fig 59 Palaeogeographic map of Gondwanaland in the middle and upper Cretaceous (After Ahmad)

sea way from the Arctic Ocean to the Gulf of Mexico Much of Mexico Venezuela and the Caribbean region was inundated During early Cretaceous the Sierra Nevada mountains were formed in western California and during the late Cretaceous the Rocky Mountains Revolution (Laramide) took place not only in North America but also along the line of the Andes mountains to Cape Horn in South America A large Wealden lake existed during lower Cretaceous in the south of England separated by a barrier of land in the north It was later invaded by the sea Glaciers covered eastern Australia Towards the close of the period there were world wide crustal deformations and mountain building movements accompanied by volcanic activity

Samples of solid rock taken from the floor of deep ocean basins are found to be

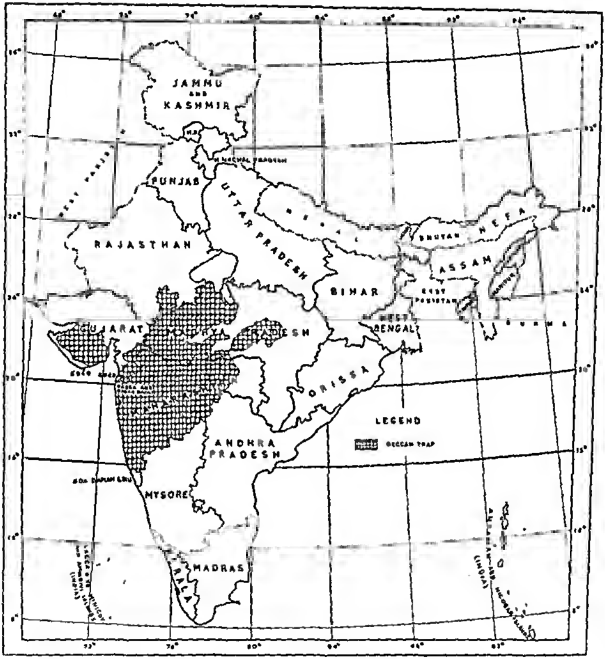


FIG. 60. MAP OF INDIA SHOWING THE DECCAN TRAP AREA IN WHICH AN ENORMOUS AMOUNT OF LAVA WAS POURED OUT BY VOLCANOES DURING THE CRETACEOUS PERIOD AND FORMED THE BLACK COTTON SOIL

not older than the Cretaceous Whether any deep sea deposits were laid in quantities during the pre-Cretaceous can only be known from deep drilling on the ocean floors Dredgings from some flat-topped sea mounts in the Pacific Ocean have yielded a rudistid coral fauna characteristic of the shallow Cretaceous Tethyan region It appears that the sea mounts were a chain of basaltic islands on which the rudistid coral fauna grew into reefs Later, the sea mounts were gradually submerged in the late Cretaceous times and finally to their present depth of 1200–2100 m Crests of major ridges, less than 1200 m deep, in Indian and Atlantic Oceans respectively are shown in Fig 61 and 62. They represent presumed sites of wider lands, which existed at least as extensive archipelagos, in the Mesozoic and early Tertiary Periods

Climate. Temperature was below normal during the early Cretaceous in North America The continent stood higher than at present, particularly in the west where high and wide mountains were formed at the time of Sierra Nevada Revolution Glacial conditions prevailed in eastern Australia During the late Cretaceous when widespread marine transgressions took place, the climate was mild with some distinction of climatic zones In Greenland, which is within the Arctic Circle now, fossil plants indicating mild climate have been found, and dinosaurs were common in Alberta Towards the close of the Cretaceous, temperatures fell again, especially in the west, because of the formation of great mountains when the Rocky Mountains Revolution took place in North America

In Gondwanaland, the climate continued to be humid even until the middle Cretaceous and possibly also towards the close of it The climate on the whole was equable

On the whole, the climate of northern hemisphere, and perhaps also of the southern, was much warmer and more humid during the Cretaceous than now This was because of the extensive invasion of the sea on all the continents as well as of the vast expanses of swamps that were formed in many places The forest swamps in Hungary, western United States Canada, Alaska and Japan gave rise to coal beds while the burial of myriads of seaweeds and other organisms in shallow stagnant waters has been responsible for the formation of oil and gas in North America and other regions

PLANT LIFE

Considerable change in plant life of the world took place with the beginning of the Cretaceous Period The progressive modernization of the flora witnessed during the Jurassic had produced recognizable forms of modern genera of all the groups of the plant kingdom Some of the lower Cretaceous plant fossils from India are shown in Pl 58

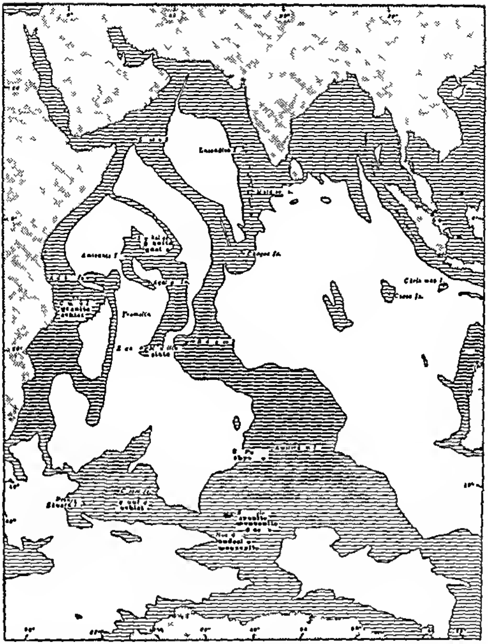


FIG 61 CRESTS OF MAJOR RIDGES (horizontal lines less than 1200 m. deep) IN THE INDIAN OCEAN REPRESENT THE PRESUMED SITES OF WIDER LANDS IN THE MESOZOIC AND EARLY TERTIARY WHICH EXISTED AT LEAST AS EXTENSIVE ARCHIPELAGOS These ridges are largely volcanic (Tertiary-Recent) underlain by older sialic rocks and are still active seismically

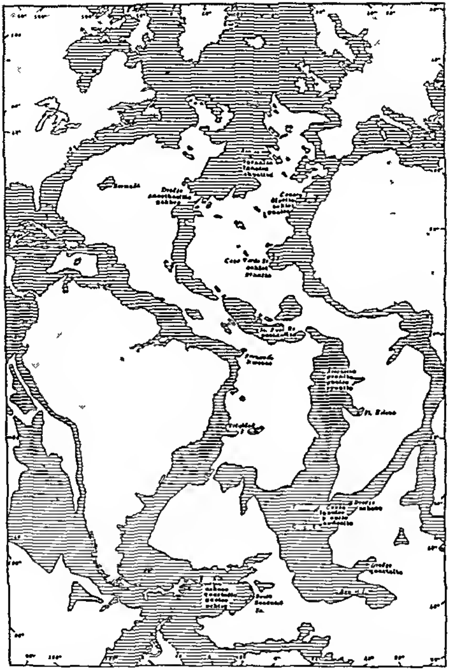
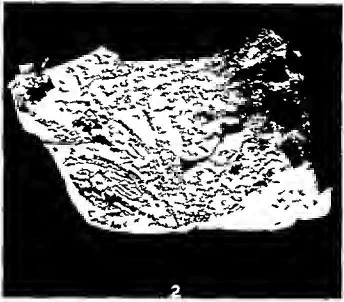


FIG. 62. CRESTS OF MAJOR RIDGES (horizontal lines, less than 1200 m. deep) IN THE ATLANTIC OCEAN REPRESENT THE PRESUMED SITES OF WIDER LANDS IN THE MESOZOIC AND EARLY TERTIARY WHICH EXISTED AT LEAST AS EXTENSIVE ARCHIPELAGOS. These ridges are largely volcanic (Tertiary-Recent), underlain by older sialic rocks, and are still active seismically

Courtesy Birbal Sahni Institute of Palaeobotany, Lucknow

SOME LOWER CRETACEOUS PLANT FOSSILS FROM INDIA

1 & 2, *Onychiopsis paradoxus* Bose & Dev.: 1, fertile; 2, sterile. 3-5, *Isoetes indicus* Bose & Roy. 6, *Isoetes serratifolius* Bose & Roy. 7, *Weichselia reticulata* (Stokes & Webb) Ward. 8 & 9, *Matonidium indicum* Sahni



1 A BRANCH OF GINKGO BILOBA A LIVING FOSSIL PLANTED IN TEMPLES OF CHINA

2, THE CLOSELY RELATED FOSSIL GENUS GINKGOITES FROM THE EARLY MESOZOIC OF RAJMAHAL HILLS

Pteridophytes

Herbaceous lycopods, especially *Lycopodium*, *Selaginella* and *Isoetes* had already appeared in the Jurassic

Equisetum, the sole survivor of the diverse Palaeozoic articulates, continued from the Jurassic to the Cretaceous and the Cenozoic

Many forms of pterophytes disappeared, leaving behind a few stragglers such as *Nathorstia alata*, a lower Cretaceous fossil from Lugo San Martin, Patagonia, showing probable marattiaceous affinities The slender and tapering pinnae of this fern, with anastomosing vein system, bore a row of densely crowded, circular synangia along each side of the midrib Although *Anemia* and *Lygodium* had already appeared, specimens looking like the Carboniferous *Klukia* still existed during the lower Cretaceous of western Canada In these specimens, the ovoid and sessile sporangia were arranged in two rows on the pinnules

Gleichenias were widespread and abundant Matoniaceae was represented by *Weichselia* and *Matonidium* *Matonidium indicum*, a lower Cretaceous form from western India, shows an upward flaring of the petiole into a funnel-shaped lamina, depicting a transitional phase to the leaf type of the Dipteridaceae (Pl 58 9)

The tree ferns during the Cretaceous referred to the genus *Tempskya* of Tempskyaceae, an extinct family, had unbranched columnar stems, 6 m. tall and up to 50 cm in diameter, tapering upwards to a blunt apex A dense mass of hundreds of small leaves clothed the upper part of the stem The trunk, especially in the middle and upper parts, consisted of many stems held together in a dense matrix of small adventitious roots

Gymnosperms

The gradually dwindling pteridosperms had vanished during the Cretaceous

The Jurassic Cycadeoids were still common during the early Cretaceous but disappeared later. Cycadales have continued to the present Coniferales, another dominant group of gymnosperms in the Jurassic, had considerably reduced An early Mesozoic conifer, *Drepanolepis*, also occurred in the lower Cretaceous It resembled *Araucaria*, and the seed-scale complex consisted of one sterile scale and one sporophyll with a single terminal inverted ovule The other important group, the Ginkgoales, was eventually reduced to a single survivor, the modern maiden hair tree, *Ginkgo biloba*, which is a living fossil and is planted in temples of China (Pl 59) Some Jurassic genera, like *Sphenobaiera* and others, however, continued upto the Cretaceous

Angiosperms

The extinction of several older groups of plants, decline of others, and the

emergence of modern forms were accompanied by the origin, progressive increase and sudden dominance of angiosperms More precisely, the angiosperm leaf impressions with the modern aspect first appeared during the mid-lower Cretaceous

Some Important Cretaceous Floras

In the early Cretaceous floras, ferns and gymnosperms dominated over the angiosperms The western Greenland flora of this age included members of Gleicheniaceae and Matoniaceae, cycads, conifers and *Ginkgo*, besides some monocots and leaf fragments of *Artocarpus, Quercus, Menispermites, Platanus* and other dicots

From Portugal, *Salix, Aralia, Braseniopsis, Myrica, Laurus, Viburnum, Eucalyptus, Magnolia* and *Sassafras* have been described. *Rogersia* and *Proteaephyllum* have been found in the Patuxent beds as minor elements in a predominantly pteridophyte-gymnosperm flora The mid-lower Cretaceous flora of western Canada includes *Populites, Ficus, Trochodendroides, Cinnamomoides, Celastrophyllum, Sapindopsis, Fontainea* and *Araliaephyllum* From England, *Aptiana, Wodburnia, Hythia, Sabulia* and *Cantia* have been described from fossil woods In the mid-lower Cretaceous deposits from Zyryanka in the eastern Siberia, USSR, about 25 per cent angiosperms have been found amongst the predominant ferns and gymnosperms Some of these are *Ranunculaecarpus, Sassafras, Cercidiphyllum, Crataegites, Dalbergites, Celastrophyllum, Zizyphoides* and *Araliaecarpus* Several of these were small-leaved

The following families and genera are known from the mid-lower Cretaceous · Araliaceae (*Aralia, Araliaephyllum*), Myricaceae (*Myrica*), Lauraceae (*Laurus, Sassafras* and *Cinnamomoides*), Caprifoliaceae (*Viburnum*), Myrtaceae (*Eucalyptus*), Magnoliaceae (*Magnolia*), Moraceae (*Artocarpus, Ficophyllum*), Fagaceae (*Quercus*), Menispermaceae (*Menispermites*), Platanaceae (*Platanus*), Proteaceae (*Proteaephyllum*), Salicaceae (*Populites*), Trochodendraceae (*Trochodendroides*), Celastrophyllaceae (*Celastrophyllum*), Sapindaceae (*Sapindopsis*), Ranunculaceae, Cercidiphyllaceae (*Cercidiphyllum*), Rosaceae (*Crataegites*), Leguminosae (*Dalbergites*), Rhamnaceae (*Zizyphoides*), etc

During the upper Cretaceous, the proportion of angiosperms in the floras showed a considerable increase over ferns and conifers The flora from the Raritan formation of New Jersey includes a few ferns, several conifers and about four-fifths dicotyledons The lower–upper Cretaceous flora from the Dakota sandstone contains a few ferns, cycads and conifers, but predominantly angiosperms Similar aspect is seen in other upper Cretaceous floras

Gymnosperms in the upper Cretaceous floras comprise Araucarias, Sequoias, Ginkgoes and cycads The following families and genera of the angiosperms are met with Myricaceae (*Myrica*), Fagaceae (*Quercus*), Ulmaceae, Moraceae (*Ficus*), Proteaceae,

Salicaceae (*Salix*), Magnoliaceae (*Magnoliophyllum*), Trochodendraceae, Menispermaceae, Lauraceae (*Cinnamomum*, *Laurus*), Rosaceae, Leguminosae, Aquifoliaceae, Celastraceae, Aceraceae, Rhamnaceae, Vitaceae (*Vitis*), Tiliaceae, Passifloraceae, Myrtaceae, Araliaceae, Cornaceae, Ericaceae, Myrsinaceae, Sapotaceae, Ebenaceae, Caprifoliaceae (*Viburnum*), Asclepiadaceae, Palmae (*Sabalites*), Rhamnaceae (*Rhamnus*), Platanaceae (*Platanus*), Fraxinaceae (*Fraxinus*) and Anacardiaceae (*Pistacia*)

By comparison it appears that several of the families and even genera are common to both the lower and the upper Cretaceous Out of 33 important families in the upper Cretaceous, 19 are those which extend from the lower Cretaceous Evidence of pollen in the Cretaceous largely substantiates the observation from megafossils that there is a progressive increase in angiosperms from the lower to the upper Cretaceous The pollen record equally brings out the occurrence of highly evolved angiosperms in the lower Cretaceous

Advances in Plant Life

The Cretaceous Period holds an important position in the geological times for the origin and immediate spread of the flowering plants, which eventually attained dominance over all other forms of terrestrial plant life The culmination of evolution to the modern forms also took place in Cycadophyta and Coniferales and even ferns Some plant groups like Bennettitales and pteridosperms became almost extinct A few early and mid-Mesozoic plant genera did pass over into the lower Cretaceous, such as *Phlebopteris* and *Laccopteris* (Matoniaceae), *Cladophlebis* (Osmundaceae), *Cyathocaulis* and *Cibotiocaulis* (Cyathaeaceae), *Baiera* (Ginkgoales), *Pagiophyllum* (Araucariaceae) and *Sciadopitys* and *Sequoia* (Taxodiaceae)

Amongst the new forms of plant life that originated, flourished and became extinct in the Cretaceous may be mentioned *Tempskya* (Tempskyaceae), sharing characters of the Cyathaeaceae, *Hemitelia crenulata* and *Todea barbara* (Osmundaceae) Similarly, *Araucariopitys americana*, a mid-Cretaceous conifer from the Staten Island, is transitional between araucarian and abietinean conifers Cephalotaxaceae also seems to have originated in the lower Cretaceous Although pines existed during the early Cretaceous, they increased in numbers in the upper Cretaceous *Prepinus*, the ancestral form of Pinaceae and a link between the pines, the cedars and the larches, existed in the lowermost upper Cretaceous at Kreischerville in Staten Island Most recent genera of conifers, cycads and ferns originated during the Cretaceous and early Cenozoic The plant life on the earth had already become as modern in aspect as it is today, although many present day species originated much later

The appearance of angiosperms ranks as one of the most outstanding strides of plant evolution during the Cretaceous We notice their gradual and progressive rise from the lower to the upper Cretaceous until the group suddenly assumes dominance over the

others and retains it until today Occurrence of stray angiospermous remains in the form of pollen, seeds, fruits, stems and leaves have also been brought to light in the pre-Cretaceous horizons The highly evolved nature of the lower Cretaceous angiosperms and their widedistribution in the upper Cretaceous have been cited to indicate the origin of this group in pre-Cretaceous periods, but undisputed factual evidences are lamentably lacking Most theories propounded have not been supported by factual evidence and practically no transitional forms are known The primitive characters in angiosperms, established through comparative morphology of modern forms, are not displayed by the Cretaceous angiosperms Even the hypothetical ancestral forms visualized by Arber and Parkin and later by Hamshaw Thomas have not found any counterparts in the Cretaceous angiosperms and plant fossils known from the earlier periods Some of the Jurassic gymnosperms, Caytoniales for instance, once regarded as the immediate ancestors of angiosperms, are no longer accorded that honour Despite numerous theories and the supposed factual evidences, the origin of angiosperms still remains an unsolved problem. It is, however, encouraging to find evidences of bisexualism, net-veined leaves, enclosed seeds, some anatomical characters of secondary wood, and furrows in the pollen of some pre-Cretaceous pteridosperms and gymnosperms, which tend to show that some of the angiospermous characters, if not angiosperms, had already originated since the Palaeozoic

ANIMAL LIFE

The Cretaceous saw some major advances in the evolution of animal life

Foraminifers

The foraminifers were extremely abundant Microscopic forms make up the bulk of the chalk deposits They also occur in vast numbers in all oil-bearing rocks and geologists engaged in search for oil, make use of them in correlating oil-bearing horizons Of the larger foraminifers, *Orbitolina* became important in the lower Cretaceous and *Orbitoides* in the upper Cretaceous

Sponges

Siliceous sponges were abundant Flint nodules of the chalk beds of England and France are the dissolved siliceous spicules of sponges, re-deposited together with silica from other organisms

Corals

Solitary corals, like *Parasmilia*, were widespread, but reef corals were more localized

than before. As in the upper Jurassic, the coral reefs were generally formed in the Tethys. No corals have been found in the lower Triassic rocks, perhaps due to cold that prevailed during the earliest Triassic. The corals re-appeared in the middle Triassic, but these including *Parasmilia* belong to an entirely new order, Scleractinia (Hexacorallia), in which the septa were in multiples of six.

Echinoderms

The crinoids became less important than in the Jurassic, but have survived to the present day by improving their feeding apparatus The food-grooves, carried on arms, now reached the surrounding water. Some sea-urchins, like *Cidaris*, maintained the radial symmetry which gave them freedom of movement in all directions, unlike some Jurassic forms, which took to the two-sided symmetry, enabling them to move in one direction only The mouth moved to the underside and its posterior margin was bent down into a scoop for mud-eating These changes were perfected during the Cretaceous Period in the heart-shaped *Micraster*, a characteristic and often the most common fossil in the upper Chalk beds.

Brachiopods

Although the brachiopods were still individually abundant, the small number of their genera, mainly of the sub-orders Terebratulacea and Rhynchonellacea, found in the Cretaceous, showed that they were on the decline.

Molluscs

In the Palaeozoic Era, the shells of coiled, single-chambered gastropods were smooth, bearing only the markings of growth lines and at times also some swollen projections as ridges or ribs In the Mesozoic Era, the surface ornamentation was intensified, not only with a delicate network pattern, but sometimes with knobs and spines developed at the points of intersection of ribs and spirals During the Cretaceous, the molluscs became more varied and numerous than in the Jurassic; and since the close of the period, there has been increasing ornamentation of the shells. Though gastropods were essentially marine, one stock took to living both in fresh water and on dry land during the period For breathing air, the mantle cavity was modified to function as a lung.

The lamellibranchs progressed well with increasing numbers, as several modes of life were opened to them. An interesting feature about the lamellibranchs was that quite unrelated types, by adopting similar modes of life, had developed similar shapes, providing an instance of the principle of parallel evolution One genus, known as *Hippurites*, adopted a sedentary mode of life. It fixed itself to the sea floor by one valve and

grew into a conical columnar, coral-like pattern about a metre or so in height by secreting limy material, layer after layer The other valve acted as a lid on the top of the column The *Hippurites* and related forms established themselves in the warm waters of the Tethys and even built reefs The fossil record of the *Hippurites* provides a classic example of convergent evolution Other characteristic lamellibranchs of the period include *Gryphea, Exogyra, Pecten* and *Inoceramus* *Gryphea* grew into a large size, while *Exogyra* developed curved, oyster-like shells Oysters were abundant, some showed a great degree of adaptation and produced a variety of shell forms smooth, thick, ornamented, and often frilled.

The ammonites were in the last stages of their existence They evolved rapidly in the late Palaeozoic, and in spite of some great setbacks became the most significant invertebrates of the Mesozoic. At the beginning of the Triassic, 10 families were known, which increased to 29 families, but nearly disappeared at the end of the period and only 2 out of the 29 families survived. These successful forms evolved in many directions and gave rise to 22 families by the end of the Jurassic, but only 8 families survived till the Cretaceous These flourished steadily with increasing numbers and varieties up to the end of the Cretaceous when they lost their vitality and fell back to the simple septal folding of the earlier times and took to uncoiling as in *Scaphites* Some even became straight, such as *Baculites* or developed irregular forms as in *Nipponites*, found in Japan and finally they died out without leaving any successors The Jurassic and Cretaceous ammonites were quite distinct from those of the Triassic, for the latter nearly disappeared at the end of the period and completely new pattern of evolution began with two basic stocks for the remainder of the Mesozoic These were the Lytoceratids (*Lytoceras*-type) and the Phylloceratids (*Phylloceras*-type) In the lytoceratids, shells were rather loosely coiled, ornamentation weak or absent, and sutures had acute denticulation of lobes and saddles The phylloceratids were similar to the lytoceratids but with a leaf-like pattern of sutures These two basic stocks dominated the Tethyan geosyncline, and the other forms which formed the great majority of the ammonites were derived from them as new stocks that inhabited the shelf seas bordering the Tethys The faunas of the shelf seas were thus continually invaded and occupied by newcomers from the Tethys Diverse and highly specialized ammonites, with comparatively thick ornamented shells, accordingly evolved in the shelf sea areas Thus from a few ancestral stocks, the ammonites of the middle and late Mesozoic progressed along numerous parallel lines "in which the constituent members reveal their common ancestry by their basic resemblance and their separate adaptations to a variety of habitats and modes of life by their detailed differences" Consequently, the ammonites afford many examples of parallel evolution

In the Jurassic and Cretaceous a genus of cephalopods, *Belemnites*, became abundant and widespread. Unlike the ammonites, their shell was internal and consisted of a

cigar-shaped solid mass of lime with only a small-chambered portion This cigar-shaped mass is called the 'guard' and is usually preserved as a fossil From its dart-like appearance it was thought to be the substance of thunderbolts and some village folk carry it about as a lucky stone. The animal did not live inside the shell but secreted a protective covering around it *Belemnites* lived in muddy waters From the impressions of the soft body, sometimes preserved in the rocks, it appears that the creature closely resembled the modern cuttlefish and had a store of sepia ink which could be ejected to envelope its foe in a 'smoke cloud', if need arose The evolution of the cephalopods seems to have progressed towards the development of mobile and active mode of life For this, the cephalopods struggled to lighten their shell or to do away with it The shell-bearing cephalopods achieved mobility as well as buoyancy through complex folding of the septal margins strengthening the shell against water pressure This, incidentally, helped keeping the body firmly fixed in its living chamber The Coleoidea group of cephalopods after a long drawn struggle, completely disposed of the shell At first the animal lived within the shell, later, the body completely enclosed the shell, as in *Belemnites*, and as time went on, the shell grew progressively smaller and smaller Shell-less forms are seldom preserved as fossils, but it seems likely that the octopus, which "with its wicked eyes and weird body, at times fired the imagination of the writers of fiction", is the culmination of the evolution among those cephalopods which got rid of their shells By discarding the doubtful advantages of a shell for speed, the octopus has attained the highest degree of sense and intelligence exhibited by the molluscs This is in accordance with an important evolutionary principle "Progress follows the lines of a reduction in number of parts and increasing specialization of the few that remain".

Insects

The winged insects first appeared in the upper Carboniferous and have since increased steadily in variety and numbers The earliest evidence of the occurrence of modern bees and flies is from the Cretaceous of Utah in USA Their entry into the world probably coincided with that of the angiosperms, indicating the inter-dependence of life The angiosperms furnish food for the insects in the form of nectar and pollen and in return the insects act as agents of pollination With the flowering plants came nuts, fruits, etc The development of insects and flowering plants during the Cretaceous was beneficial to the small mammals and birds who could now live on the highly concentrated products of flowering plants or on the insects subsisting on these plants With the rise of the flowering plants, the mammals and birds moved steadily towards complete ascendancy

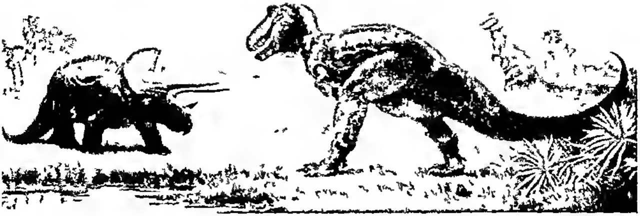
Fishes

In the realm of fishes, the teleosts completely displaced their more primitive holostean ancestors from the oceans of the early Cretaceous Period. The teleosts had first appeared late in the Jurassic. The main reason for their success was that their skeletons became completely bony, a feature that afforded a strong framework for the attachment of muscles Their scales, though remained thin, were sufficiently strong to give them ample protection

Reptiles

Such reptiles which survived the drought of the Triassic and entered the Jurassic, distributed themselves in the Cretaceous on land, and in the air and sea Many were unsuited to survive in the great struggle for existence and contrived to live with a covering of defensive armour *Triceratops* was typical of the herbivorous dinosaurs which specialized in a defensive armour They were huge animals, more than 6 m in length and standing 3 m high, with three horns, each more than a metre long They developed bony frilled shields to protect the head and neck and when attacked, would stand in defence and wait until their foes would be transfixed on their horns (Pl 60)

Other herbivorous dinosaurs included *Trachodon* or duck-billed dinosaur and *Ankylosaurus* or armoured dinosaur *Trachodon* was about 9 m in length and stood about 5 m high It had a powerful crocodile-like tail and it lived partly on land and partly in water *Ankylosaurus* was about 6 m long and its low dumpy body was completely protected by long plates that extended into spikes (Pl. 61) *Iguanodon* was a gigantic reptile, so named because of its teeth which resembled the modern lizard, iguana, found in tropical America It was about 15 to 20 m long and 5 to 6 m in height and its formidable skeleton is shown in the British Natural History Museum The flying reptiles species of *Pterodactyl*, reached their maximum dimensions from the size of a sparrow to giants with wing spread of about 9 m Some forms allied to *Pterodactyl* probably had wings too weak to raise the heavy body through the air so that they could not fly well, and their legs were also too weak to carry the great weight, and hence they could not walk satisfactorily They could not comfortably sit down either, because the elbows would get in the way, unless they sat perched on the top of a cliff from where they could float in the air like gliders to swoop down upon the prey and then laboriously climb the cliff again The carnivorous *Tyrannosaurus* was the king of dinosaurs (Pl 60) It was 10 to 16 m long and when standing on its hind legs, its head would rise 6 m up in the air Its small arms were provided with vicious claws and the mouth with huge teeth for tearing flesh Its 6 m long tail balanced the body and was used as a club for fighting



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GIANT CRETACEOUS DINOSAURS FROM WESTERN NORTH AMERICA

The largest flesh eating dinosaur known was Tyrannosaurus two of which are shown attacking the herbivorous, horned dinosaur, Triceratops

Painting Charles R. Knight; Courtesy Chicago Natural History Muse

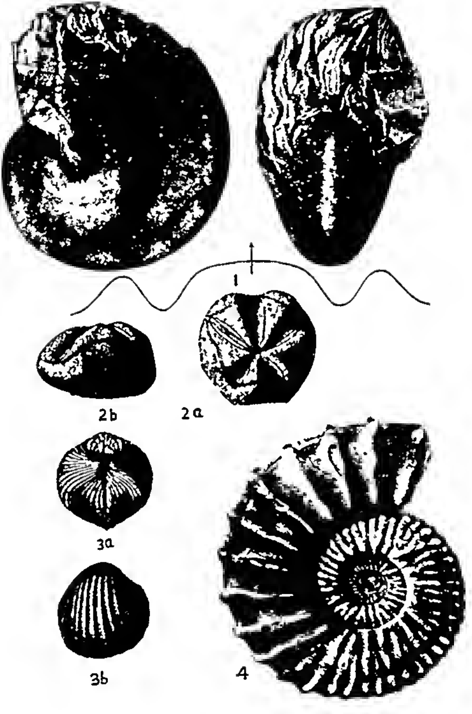
WESTERN CANADA IN THE CRETACEOUS PERIOD

The land was low, well watered and covered with numerous swamps. Most of the dinosaurs were harmless, plant-eating forms of the Ornithischia group of reptiles, characterized by bird-like pelvic bones. Two types of duck-billed dinosaurs can be seen—three large, uncrested ones to the right, and two types of crested ones in the left background In the middle foreground is a heavily armoured, four-footed dinosaur covered with bony plates and spines. In the centre background are two ostrich dinosaurs—tall, slender animals with the general proportions of an ostrich, but with short forelegs and a long, slender tail

Painting Charles R Knight Courtesy Chicago Natural History Museum

DURING MUCH OF THE CRETACEOUS PERIOD, A SHALLOW INLAND SEA COVERED THE WESTERN HALF OF THE MISSISSIPPI VALLEY

Three reptiles characteristic of this time and place are shown in the centre is a large mosasaur, about 9 m long, to the right is a marine turtle, and flying in the left background are a number of reptiles of the genus Pteranodon



Courtesy GSI Calcutta

SOME CRETACEOUS ANIMAL FOSSILS FROM INDIA AND NEIGHBOURING COUNTRIES

1, *Nautilus* (*Hercoglossa*) *danicus* Schloth 2 (a & b) *Hemiaster oldhami* Fourt 3 (a & b) *Cardita* (*Venericardia*) *beaumonti* d Arch & H, 4 *Schloenbachia inflata* Sow (1 & 4 Cephalopoda 2, Echinoidea 3 Lamellibranchiata)

In the seas, ichthyosaurs and plesiosaurs continued to live, though lesser in numbers. They were joined by highly specialized marine reptiles, called mosasaurs, which were gigantic long-tailed marine lizards (Pl 62).

Space forbids mention of other bizarre forms of dinosaurs The problem of most particular interest is their sudden disappearance The events that marked the close of the Cretaceous had their bearing on these animals. There were mountain building activities and fall of the sea level on a vast scale resulting in general dryness and elimination of swamps in most places Many organisms which were unable to adapt themselves to the changed environment died out, while others survived by undergoing modifications to suit the new conditions The dinosaurs were an ancient race that had passed their prime of life by over-specialization with the development of huge external defensive armour without corresponding development of brain and nerves *Triceratops* had a skull 2 m long, but its brain was of the size of a kitten's Most forms were adapted to a particular type of environment and the change to new conditions came about so suddenly that they found little time for adjustment to circumstances and, therefore, became extinct. Only the simplest types, succeeded today by the lizards, crocodiles, turtles and the legless snakes, survived.

Mammals

The scarcity of fossil remains of mammal-like reptiles makes it difficult to assess their development in the Cretaceous Period Their teeth suggest that there were two groups, one of plant-eaters, and the other with sharp teeth, apparently of flesh-eaters They were small animals resembling modern hedgehogs or shrews and sufficiently hardy to survive the changing conditions and to assume the supremacy which the dinosaurs previously had It is probable that they were the ancestors of pouched animals known as Marsupials, of which the opossums are modern representatives in South America and New Guinea, and kangaroos in Australia Kangaroos reached Australia before the middle of the Cretaceous, when land connection between Australia and South East Asia was severed. Placental or more advanced type of mammals also originated before the close of the Cretaceous

Cretaceous Fauna of India and Neighbouring Countries

The Pondicherry–Tiruchirapalli sector is of great palaeontological interest as it contains more than 1000 species of extinct organisms which include polyzoa, crinoids, echinoids, corals, brachiopods, lamellibranchs, ammonites, gastropods, fishes and dinosaurs The lamellibranchs and gastropods are the most abundant. Ammonites form the most important part of the fauna with 150 species.

These rocks, from the base upwards, are divided into four principal stages ·

(1) Utatur stage, consisting of fine silts, calcareous shales, sometimes with a coral

limestone Ammonites number 100 species and include species of *Schloenbachia*, *Acanthoceras*, etc. besides *Nautilus neocomiensis*

(2) Tiruchirapalli stage containing sands, clays and shore beds intercalated with shell limestones There are 27 species of ammonites belonging to *Pachydiscus*, *Scaphites*, etc.

(3) Ariyalur stage, chiefly made up of white and green sandy strata, usually unfossiliferous, but towards the upper and lower parts of the succession, there are calcareous grits and shales full of fossils Ammonites are represented by over 50 species belonging to the genera *Pachydiscus*, *Baculites*, etc. Among the numerous lamellibranchs and gastropods, the Cypraeidae and Volutidae are particularly well represented

(4) Niniyur stage constituting the uppermost bed with characteristic Danian fossil, *Nautilus (Hercoglossa) danicus*

The fishes are represented by 17 species The dinosaurs are well represented but unfortunately are too fragmentary for reconstruction Families represented include Titanosauridae, Allosauridae and Ornithomimidae Three Indian sauropods occur also in South America, in the younger beds, suggesting direct land communication between the two countries No Cretaceous mammals have yet been found in India

In Baluchistan and Sind, the lowest Cretaceous beds, known as 'Belemnite beds' contain abundant *Hibolites subfusiformis*, similar to forms found in the corresponding beds in Malagasy In the succeeding beds are found *Sphenodiscus*, *Pachydiscus*, *Inoceramus*, *Hippurites*, etc known from rocks of similar age in Europe. The top beds are characterized by *Cardita beaumonti*, a lamellibranch with a globose shell The Belemnite beds extend into the Salt Range of Pakistan through Waziristan Here, *Hibolites subfusiformis* is the most characteristic fossil which occurs associated with *Neocomites*, *Blanfordiceras*, etc allied to the forms in the Mediterranean and Malagasy *Blanfordiceras* also occurs in the Spiti shales in the central Himalayas together with *Belemnites*, *Hippurites*, and foraminifers

In Assam the Cretaceous of Khasi hills contain *Pachydiscus*, found also in the Pondicherry–Tiruchirapalli sector *Neocomites*, *Schloenbachia*, *Acanthoceras*, *Pachydiscus*, *Inoceramus*, etc of the Pondicherry–Tiruchirapalli sector have also been recorded from the Indonesian region Not much information is available on the Cretaceous rocks of Burma but *Cardita beaumonti* has been found in the Arakan Yoma, though no ammonites are recorded. Some of the Cretaceous animal fossils from India and neighbouring countries are shown in Pl. 63

THE CENOZOIC ERA

CHAPTER FOURTEEN

THE TERTIARY PERIOD—I

Palaeogeography

With the disintegration of Gondwanaland towards the end of the Cretaceous, the continents acquired their present features, their shapes, the great mountain systems, the courses of the rivers, the great plains, and the climatic zones The Cenozoic Era that followed the Mesozoic is continued up to the present It began about 60 million years ago and is relatively a short period in terms of geological time and the history of evolution of plants and animals

Cenozoic Era is divided into two periods—the Tertiary and the Quaternary The Tertiary is sub-divided into five Epochs The name of each epoch ends with the suffix, *cene* (Greek—recent), and refers to the progress of life Originally it was done on the basis of the percentage of living species of molluscs found in the rocks, but later, certain marked palaeontologic characters as well as physical events were included The Tertiary Period has been studied in greater detail than any other period partly because its flora and fauna bear close similarities to the living forms, but mainly in search of petroleum, of which more than 50 per cent of the world production comes from the Tertiary rocks

The sub-divisions of the Cenozoic Era are shown below with their approximate durations

Cenozoic Era	Quaternary Period	Recent Epoch	10,000 years	Neogene Period
		Pleistocene Epoch (most recent)	1 million years	
	Tertiary Period	Pliocene Epoch (more recent)	7 million years	
		Miocene Epoch (less recent)	12 million years	
		Oligocene Epoch (little recent)	15 million years	Paleogene Period or Nummulitic Period
		Eocene Epoch (dawn recent)	15 million years	
		Paleocene Epoch (ancient recent)	10 million years	

The continent of Gondwanaland had already split up into its integral parts towards later part of upper Cretaceous The drifting apart of continents was facilitated by the great overflow of lavas, such as the Stromberg lavas of South Africa, the Serra Geral volcanics of South America and the Deccan traps of India As a result of these earth movements, considerable parts of the marginal areas of Gondwanaland broke off and sank into the oceans The Tethys had already been shallowed in the upper Cretaceous The intermittent mountain building continued throughout the Tertiary, as a consequence of which the great equatorial mountain systems such as the Atlas, the Pyrenees, the Alps, the Caucasus, the Himalayas and the Malay Arc were formed (Fig 63).

The Tertiary, in most continents, was a period of earth movements, mountain building and volcanism The most affected regions were the Tethys and the land bordering the Pacific Ocean The region that suffered from greatest disturbances is south-east Asia which lies at the junction of the great Tethyan zone of disturbance and the circum-pacific girdle of volcanoes and earthquakes Here, continued crustal unrest resulted in repeated uplift and subsidence of land and frequent volcanic outbursts The West Indies in the Caribbean region, was also affected by crustal disturbances and volcanism The sea

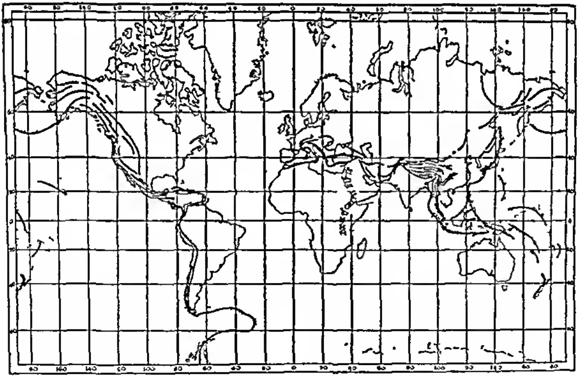


FIG. 63. MAP OF THE WORLD SHOWING THE HIMALAYAS THE ALPS, THE ROCKIES AND THE ANDES WHICH WERE UPLIFTED DURING THE TERTIARY PERIOD (From Peake & Fleure)

advanced over the Gulf Coast, and as the Mississipi delta grew seaward, the bottom of the Gulf of Mexico subsided to receive about 12 200 m. thick Tertiary sediments in eastern Texas and Louisiana Plugs of rock salt or salt domes, as they are called, penettated into the overlying strata of the Gulf coast The major oceans remained without much change There were, however, frequent encroachments of the seas over the coastal areas

In India and the neighbouring countries, Tertiary deposits are widely distributed and can be traced continuously from the Makran coast of Baluchistan through the Himalayas to eastern Assam and then to the Arakan region in Burma In peninsular India, they are found as scattered outcrops along the east and west coasts

The type areas of the early Tertiary deposits for India are in Sind in Pakistan Here, the Paleocene is represented by the Ranikot beds The marine Eocene beds are seen more or less continuously in Pakistan from the Arabian Sea northwards, through Sind, Baluchistan and the North-West Frontier to the Salt Range and the Kala Chitta hills of the outer Himalayas, and in India from Jammu to Garhwal along the southern base of the Himalayas On the west side of the Peninsula, marine lower middle Eocene is known around Surat and Cambay, and across the Gulf of Cambay in Kathiawar and Kutch In Rajasthan, the Eocene rocks fringe around the Jurassics in Jaisalmer, and also occur in the isolated area in Bikaner where lignite is mined In Assam, the Eocene is represented by Jaintia rocks in the southern and eastern parts of the Shillong plateau, and by the Disang beds in upper Assam The Andaman and Nicobar belt of the Eocene rocks stretches to upper Burma through the Arakan Yomas on the one hand and to Indonesia on the other The Oligocene is unrepresented in the Himalayan region The Oligocene deposits, however, occur in Sind and Baluchistan in West Pakistan, and in Gujarat, Assam and Andamans and Nicobars in India, and in Burma The marine lower Miocene formations adjoining the Arabian Sea in Sind and western India are known as the Gaj Series They are known to interdigitate with the Manchhars of West Pakistan The Manchhars are partly estuarine, but mostly fluviatile. Further north, the Miocene is present as fresh- to brackish-water deposits comprising the Murree Series of the Potwar plateau in West Pakistan and their equivalents known as the Dagshais and Kasaulis of the Himalayan foothills in the Simla area

From upper Assam along the front of the Naga hills, and passing into East Pakistan and the Arakan coast of Burma, the Surma Series is lower Miocene and at least partly marine Shallow marine fauna of lower middle Miocene occurs south of the Garo hills, and an equivalent is known in Orissa, beyond the Bengal alluvium while the Quilon limestone in Kerala is now regarded as probably about middle Miocene. The principal Tertiary deposits of western and northern India are the fluviatile Siwaliks with well known vertebrate fauna. The Siwalik system (middle Miocene to lower Pleistocene) forms

the low outermost hills of the Himalayas along the entire length from the Indus to the Brahmaputra In the east, the Tipam Series of Assam continues the Surma sequence, but is non-marine in Indian territory, and becomes marine along the Arakan coast of Burma The Cuddalore and Rajahmundry sandstones of the east coast and Warkalli beds of the Kerala coast may be late Miocene or early Pliocene

The formation of the Deccan trap, to which reference has been made earlier, continued in the Tertiary Period. By far the greater part of western India is made up of the Deccan trap covering an area of 322,900 sq km Originally it had a much greater area, probably covering 800,000 sq km, outlying patches of the trap occur in Sind, Kutch Bihar, and coastal areas of Andhra Pradesh The Deccan trap is known to be younger than the middle Cretaceous, for near Hyderabad, West Pakistan, drilling for oil has shown that the base of the trap lies just below the *Cardita beaumonti* bed of upper Cretaceous age On the other hand, most of the trap of the peninsula proper has been referred to the Eocene or even to the Oligocene as it rests on the lacustrine Lameta beds near Jabalpur containing fossil fish remains indicating a lower Eocene age, and marine intercalations in the eastern margin near Rajahmundry in Andhra Pradesh certainly suggest an Eocene age Thus, the formation of the Deccan trap began in the uppermost part of the middle Cretaceous and continued into the Eocene or even later A few crater-like forms are seen in Girnar hill, Rampur, Dhank, and Chogat-Chamardi in Gujarat, and near Bombay

In Maharashtra, the Sahyadri mountains, known as the Western Ghats, are made up of the Deccan traps which attain a thickness of over 2100 m (Pl. 57) The parallelism of the Western Ghats escarpments to the sea coast suggests some connection between the two The trap which must have once stretched westwards over a large part of the Arabian Sea, may have been submerged beneath the sea by a system of parallel faulting Sir Edwin Pascoe has remarked that the relics of this sunken portion of India, with remnants of relief features still preserved, have in fact been located below the Arabian Sea by the John Murray Expedition A mollusc, named as *Cremnoconchus sahyadrensis* by W T Blanford, lives on vertical rocks kept wet by the spray of waterfalls It is unknown anywhere else and is so closely related to Indian forms of the littoral marine genus, *Litorina*, as to have a common ancestry, indicating that the Western Ghats were once washed by the sea If this is so, then there must have been a long period of erosion since the scarp was a sea-cliff, and was produced by faulting in early Tertiary times And later, a general uplift of the coast as a whole at a comparatively recent date has been responsible for the formation of the narrow, regular, low-lying strip in Maharashtra and Mysore, known as the Konkan Pascoe thinks that it is possible that the isolation of various plateaus in southern India, and the denudation of the Palghat Gap, south of the Nilgiri plateau,

are due in part to the marine invasion of the same date as the formation of the Ghats' scarp The formation of the west coast must date from some epoch prior to lower Miocene, since marine lower Miocene deposits, known as the Gaj beds, occur in Gujarat, and in Sind, West Pakistan

At the close of the Deccan Trap Period, earlier than the formation of the Gaj beds, land conditions prevailed further west beyond the present coast line South of the Deccan trap country, the absence of any large valleys in the peninsula draining westward indicates that the present position of the shore line is of more recent origin than that of the east coast The easterly trend of most of the peninsular drainage is probably of very old age, and as shown by its marginal patches of Cretaceous and Tertiary marine sediments, the east coast has been maintaining more or less its present position since lower Cretaceous times

In the extra-peninsular region, large masses of granite penetrated the central Himalayan region, mainly at the end of the Eocene and in the Miocene during the upheaval of the Himalayas

Eastern Hemisphere

Paleocene-Eocene Perhaps the most intense crustal movements in the Tertiary history of Eurasia were in the Tethyan region These movements resulted in the formation of the Alpine-Himalayan mountain system In Europe, following the great marine transgression at the end of the Cretaceous, the North Sea once again spread over the whole of north-west Europe, burying under its water Denmark, Holland, Belgium, north-western France and south-eastern England In the Paris Basin, alternating marine and non-marine depositions took place during Paleocene to Oligocene times In the south, the Tethys held its sway over the countries bordering the present day Mediterranean Sea and had established a connection with the Atlantic across southern Spain and Morocco Through the Middle East, it spread into West Pakistan, western India Kashmir and in the main region of the Himalayas to as far as Lhasa in Tibet On the eastern side of the Urals there was a sea-way from the Tethys joining the Arctic.

Earth movements during late Eocene uplifted the central axis of the Himalayas and the sea retreated southwards from the two ends of the rising Himalayas There were thus two principal gulfs, the Sind-Baluchistan gulf extending through Gujarat, western Rajasthan Punjab, Simla and Nepal, and the eastern gulf, sub-divided by the Arakan Yoma ridge into the Assam gulf and the Burma gulf These two gulfs of Assam and Burma became more and more widely separated from each other by the continued uplift of the Arakan Yoma and the Naga hills Extensive deltas spread out at their upper reaches Fig 64 shows India and the adjacent countries during late Eocene.

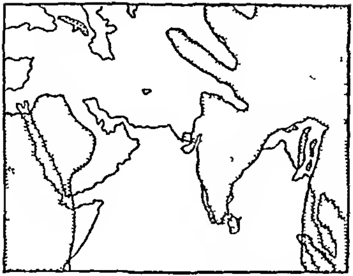


FIG 64 MAP OF INDIA AND THE ADJACENT COUNTRIES DURING THE LATE EOCENE

Much of Indonesia was land and so was Australia throughout the Cenozoic, except for some minor encroachments of the sea along the north and south coasts of the latter. During these epochs, there were a few marine embayments In New Zealand, the earliest Cenozoic seas seemed to have spread over the eastern side of the South Island and North Island, and by the middle Eocene, the sea spread further inland in South Island and also flooded its western coast

Oligocene. The sea advanced and retreated along the margins of the continents Uplift of land was more prevalent than subsidence The uplift of land resulted in the creation of lagoons, islands and lakes The south-eastern coast of England and the Paris Basin became dry land, but a wide sea-way extended from the Caspian Sea across Poland and Germany joining the North Sea with the Tethys The Alps came into existence, and with their emergence the end of the Tethys started in the Mediterranean region. To the north of the rising Alps, the sea was narrow and became lagoonal In central Europe, stream and lake deposits were formed at some places between the Tethys, the North Sea and the Atlantic There were also faulted basins within the Hercynian massifs where Oligocene sedimentation gave rise to lacustrine deposits Turkey and parts of Iran rose from the sea bottom The Himalayas, which had started rising above the Tethys, were further folded South of the Himalayas, a large fresh- to brackish-water basin developed. The Sind-Baluchistan gulf retreated from the Himalayan region and northern Punjab until its head lay south of the Bugti hills in Baluchistan Thus, in the Oligocene

and succeeding Miocene times there was sea in Sind–Baluchistan, Kutch–Cambay and western Rajasthan The Assam and Burma gulfs persisted but the sea retreated southwards being replaced by fluviatile deposits In West Pakistan, western India, Assam and Burma, accumulation of organic matter under different conditions gave rise to the formation of coal and oil The communication between the Indian seas with the Tethys of southern Europe must have been well maintained till the middle of Oligocene, since the faunal relations between the two regions persisted and in fact increased during the lower Oligocene Much of Indonesia was flooded There was volcanism in Sumatra, Java, Borneo, Japan and Korea and in the Caspian Sea region

In Africa, the close of Oligocene witnessed the emergence of Algeria and Tunisia There was some volcanism in Libya

During the Eocene and Oligocene, extensive lake basins occupied eastern Australia and Tasmania

Miocene. In the beginning of the Miocene Epoch there was some advance of the sea, but on the whole, this was an age of mountain building and general uplift All the great mountains of the present day were either born or rose by appreciable heights The site of the Pyrenees which was a mere foreshore of a sea-way that separated Spain from France in the Oligocene was filled up with the shells of dead nummulites and gradually rose up to an east-west range The Alps, already born in the Oligocene, grew bigger, the Apennines came into existence as also the Dinaric Alps, the Balkan mountains and the Carpathians, as well as the Caucasus During most of this epoch Great Britain remained above the sea The North Sea was limited to a gulf between Scandinavia and British Isles There was no English Channel The Tethys shrank in size and an inland sea came into existence on the north of the Alpine chain, and stretched from southern France through the Danube basin to southern Russia Anatolia (Turkey), Arabia, etc. continued to be land areas Some isolated marine and fluviatile basins that came into existence earlier also persisted and new ones sprang up in Spain, Germany, Poland, Algeria and Tunisia The Mediterranean Sea remained connected with the Arabian Sea across Iraq and Kuwait The lower Nile was submerged beneath the Mediterranean Sea, which advanced to Cairo and beyond

On the coastal areas of Sind and along the Cambay region, marine conditions prevailed Elsewhere in Sind and in the depression formed in south of the rising Himalayas, a combination of rapid uplift and subsidence caused the deposition of 4500–6000 m. thick fluviatile sediments over the fresh to brackish Murrees (lower Miocene) This great thickness of terrestrial sediments derived from the erosion of the rising Himalayas are known as the Siwalik system It records the sedimentation from middle Miocene to

lower Pleistocene and has yielded a variety of fossils indicating a wide range of climatic conditions, from humid to arid

Middle Miocene to lower Pleistocene—The Siwalik System. The Siwalik system has been divided into three divisions as follows:

Upper Siwaliks	Boulder Conglomerate Beds	First Glaciation
	Pinjor sandstones	Lower Pleistocene
	Tatrot sandstone . ..	Pliocene
Middle Siwaliks	Dhok Pathan—Gravels, brown sandstones, shales and clays	Upper to middle Miocene
	Nagri—Grey sandstone and shales	
Lower Siwaliks	Chinji—Bright-red shales and sandstones	Middle Miocene
	Kamlial sandstones	

The Siwalik or Indobrahm river. From the north-eastern corner of Assam, a mighty river flowed in the western direction along the foot of the Himalayas as far as the Potwar or Rawalpindi plateau, a basin in West Pakistan, where it joined the Indus which emptied itself in the Arabian Sea then lying further inside Sind This river has been called the "Indobrahm" or the Siwalik river It received on its right bank the rivers of the Gangetic system as well as the Punjab rivers of the Indus system On its left bank, it might have received the ancient Son, Chambal, etc from the peninsular India The mighty Indobrahm flourished from the Miocene to the Pliocene for about 20 million years During this period, its basin, 6000 m deep, was filled with mud sand gravel boulders, logs of wood and skeletons of dead animals that lived in the neighbourhood An excessive thickness of sediments accumulated as the basin was gradually sinking in response to the rising Himalayas in accordance with the principle of isostasy

Although there can be no doubt about the existence of Siwalik river from the vicinity of Naini Tal to the Arabian Sea, its continuation further eastwards along the whole length of the Himalayan base to Assam is less substantiated. The estuarine clays at the western end of the Garo hills suggest that the drainage of eastern Nepal and Sikkim passed through the gap between the Rajmahal and Garo hills Similarly, the clays at the far end of the Shillong plateau indicate the outlet for the upper Assam rivers Recent geophysical investigations have indicated that the Garo-Rajmahal gap is underlain by two or more

segments of basement rocks separated by narrow and fairly deep sedimentary troughs The area between the Shillong plateau and Bhutan was probably still relatively elevated during early Neogene times, for there is no evidence of the deposits of this period north of the Brahmaputra

The fauna provides a glimpse of the geographical conditions that generally prevailed during the Siwalik Period in the riverine tracts along the foot of the rising Himalayas The dinotheres and primitive trilophodonts were water-loving animals, characteristic of warm and humid lowlands, because their teeth were adapted to eating only succulent herbage Occurrence of the aquatic tragulids and hippopotamus suggests the presence of rivers A savannah or swamp type environment is indicated by *Hipparion*, whose broad hooves were exceptionally adapted to it, while *Equus* was better adapted to harder ground and harsher herbage The presence of antelopes indicates prairies, steppes, or desert, while goats and oxen, with "cloven hooves" were suited for moving on the soft forest soils The majority of the pigs and canidae were forest dwellers, though a few from the Chinji to the Dhok Pathans show striking adaptation to the growing arid conditions *Giraffokeryx* had preference for forest, and the giraffes, with their characteristic feet and teeth structure, for open grassland with scattered trees In the words of Edwin Pascoe, "In general, therefore, we may visualize during most of the period, belts of luxuriant forest and open grass plains, with a great river winding through one or the other"

In the Gulf of Assam, the Himalayan movements led to limited uplifts and erosion followed by subsidence In Burma, marine sedimentation continued southwards as the delta grew seaward.

The parallel north-south ranges that are now seen in Burma and Indo-China and between which flow the Mekong, the Salween and the Irrawaddy rivers were upheaved by the crustal movements of this age

The uplifts in south-east Asia raised the Celebes, Borneo and New Guinea from the sea floor In New Zealand, Mount Cook received its main uplift Australia being made up of highly consolidated ancient rocks was unaffected by any major uplift

The elevation of land at the expense of the sea continued during the Pliocene Epoch, though there were also some subsidences here and there All the continents assumed more or less their present shapes The Pliocene seas were much smaller than those of the Miocene There were many small basins and widespread areas of terrestrial deposition. In Europe, the inland brackish sea which extended from the Danube basin to southern Russia in the late Miocene, was broken up into the Aralo-Caspian Sea and Black Sea, and the freshwater basins, like the Pannonian basin lying between the Carpathian and Balkan mountains and the Euxine basin which marks the present site of the Black Sea,

came into existence The East German-Polish basin also remained as a freshwater lake. The North Sea was formed by subsidence in north-western Europe. Some volcanism prevailed in France and Germany In Africa the Pliocene Sea occupied some marginal areas of Algeria and Tunisia

In India, Pakistan and Burma, land conditions prevailed except for some limited invasion of the sea in the coastal areas. Uplift of the Himalayas continued and ice caps began forming on the high elevations

In Indonesia, the northern parts of Java and Sumatra were under the sea. There were also active volcanoes in these islands as well as in Borneo

Australia except for some marginal adjustment, remained unaffected New Zealand, however, suffered from the crustal disturbances and volcanic activity.

Western Hemisphere

North and South America assumed their present day outlines, but remained separated until the Pliocene During the early Tertiary, the Appalachians, the Rockies, and the Andes were already in existence They grew in height and the structural basins formed between the mountain ranges during their uplifts began to be filled up with sediments derived from the weathering of the adjacent ranges The Pacific coast was still a weak zone of the earth's crust and was subjected to various crustal disturbances Here, the marine sediments were folded up to form the Coast Range, while accumulation of immense lava flows gave rise to the Cascade Range A complete sequence of Tertiary freshwater deposits of North America is found in the western states of the United States The rocks are fossiliferous sandstones and shales The Paleocene deposits are found in the plains of Montana, in the Dakotas, in the Big Horn Basin of Wyoming and the San Juan Basin of New Haven The Eocene lake deposits, known as the Green River formation, developed in the adjoining areas of Colorado, Utah and Wyoming are famous not only for their great reserves of petroleum, but also for fossil remains of plants and animals During the Oligocene Epoch, a vast thickness of sediments was deposited in the foothills and plains of Wyoming, Colorado, Nebraska, and South Dakota entombing the remains of numerous generations of mammals and plants On the Pacific coast, sea advanced and retreated over much of Washington, Oregon and California states during the Miocene Epoch, giving rise to valuable petroleum fields On the Columbia plateau in the north-western part of the United States, the outpouring of basaltic lava began in the middle Miocene time and probably continued into the Pliocene and beyond Like the Deccan trap, these lava flows form one of the world's greatest lava fields The close of the Tertiary saw the uplift of the Coast Range of California and Oregon and the Cascade mountains in Oregon and Washington

The southern plains of Argentina were flooded by the sea several times, otherwise in South America there were only marginal encroachments of the Tertiary seas The west coast of South America witnessed both volcanism and sedimentation whereby land was added to the Andes

Climate. General fluctuations of climate during the Tertiary comprised progressive warming up from the lower Eocene, approaching maximum warmth in later Eocene, Oligocene and early Miocene when besides warm, the wet and humid climate existed and supported tropical rain forests From the upper Miocene to the Pliocene, the climate gradually cooled again and progressively approached its climax towards the close of the Pliocene In this general trend of climatic changes, it may be remarked that the warm to wet tropical climate almost uniformly existed all over India during the early and mid-Tertiary and it was more moist than now

CHAPTER FIFTEEN

THE TERTIARY PERIOD — II

Plant Life

The Age of the Angiosperms

By the close of Mesozoic Era, all the modern groups of the plant kingdom had evolved, and the angiosperms amongst them, attained widespread dominance over the other groups During the Cenozoic, comprising a span of about 60 million years, no new groups of plants came into existence and evolution chiefly proceeded into two directions, namely the modification of older genera and species into modern forms, and shifts in plant populations in response to climatic, edaphic and physiographic changes. The present distribution of plants and the vegetational patterns has slowly and gradually evolved out of the Tertiary flora, which so far as specific determinations are concerned, was far different from the modern flora, but most of the modern genera have been recognized to have had their origin in the late Cretaceous or the early Tertiary It is largely on this assemblage of genera in the Tertiary flora that the climatic inferences are based That the extinct species might have had entirely different climatic requirements than the present ones, is an important fact that should always be borne in mind. But the exclusive occurrence of the fossils of modern genera of tropical or temperate climate, in a region where arctic climate prevails today, is a proof of milder climate in that region in the past

Arctic and Antarctic Regions

The Tertiary plant fossils discovered from Spitzbergen, Greenland and Alaska in the Arctic, and from the Palmer Peninsula in the Antarctic, which are perpetually snow-bound at present, show the occurrence there of a much milder climate during this period. The Tertiary plant life in Brogger Peninsula was dominated by *Sequoia longsdorfii*, *Metasequoia occidentalis* and *Cercidiphyllum arcticum* *Taxodium* and *Taiwania* together with *Ginkgo* were also present Besides the aquatic *Acarus brachystachys*, species of *Hamamelis*, *Acer*, *Aesculus*, *Planera*, *Alnus*, *Vitis*, etc comprised the vegetation Pollen of palms, *Abies* and *Sciadopitys*, and spores of Osmundaceae and Polypodiaceae have also been recovered from the sediments

The Tertiary flora of Iceland consisted of horsetail, pine, alder, birch, hazel-nut, oak, elm, sycamore, etc and that of Alaska comprised several members of Amentiferae such as poplar, willow, *Myrica*, birch *Carpinus*, *Alnus*, *Fagus*, *Quercus* and elm, together with Piper, *Engelhardtia*, *Artocarpus*, *Grevillea*, *Magnolia* and members of Lauraceae, Papilionaceae, Vitaceae and Elaeocarpaceae The palm, *Flabellaria florissanti*, has been found in south central Alaska in Matanuska coalfield The occurrence of cycads (*Dioon*, *Ceratozamia*), conifers (*Taxodium*, *Metasequoia*) and several ferns indicates a milder climate

Europe

Tertiary floras, ranging in age from the Eocene to the Pliocene, are known from various parts of Europe The lower Eocene flora of Europe is predominantly an angiosperm flora with only seven conifers The London Clay flora comprised 100 genera, out of which 28 are still living Amongst the natural orders represented, 5 are entirely tropical, viz Nypaceae, Burseraceae, Icacinaceae, Bixaceae and Sapotaceae, 14 are almost exclusively tropical, viz Palmae, Oleaceae, Menispermaceae, Annonaceae, Lauraceae, Meliaceae, Anacardiaceae, etc., 21 are equally tropical and extra-tropical, and 5 are chiefly temperate Lauraceae are represented by 40 species and Icacinaceae by 21 species The London Clay flora closely compares with the modern flora of the Indo-Malayan region Representatives of modern European flora are wanting This flora contains the lowland tropical to the mountain tropical or extra-tropical forms

The upper Eocene flora from the Hordle beds of Hampshire, England, is dominantly southern Asiatic, especially of South China and Burma regions Besides the Japanese, North Chinese and Himalayan elements, northern elements with European affinities, such as *Salvinia*, *Pinus*, *Potamogeton*, *Limnocarpus*, *Stratiotes*, *Corylus* and *Rubus* are also present

The Oligocene, Bembridge flora, from the Isle of Wight, has plants of more northerly affinities, suggesting a warm temperate climate. These include the Leather fern *Acrostichum* which is also found in southern Florida and the Keys, *Acanthus*, allied to the species found in the mangroves of Asia and Australia, and several others, showing relationships with their modern forms in the Malay Peninsula

The progressive shift from eastern Asiatic affinities to west European is seen in the Pliocene plants such as in the Pon-de-Gail, Reuverian, Krosienko, and Teglian floras Besides the European forms, the Reuverian flora contains several western Chinese elements, as well as some Japanese, Malayan and Tibetan The flora from Krosienko in southern Poland has 18 per cent species closely related to modern European, 37 per cent to eastern Asiatic and 19 per cent to eastern American floras Of the two distinct elevations represented in the flora, the lower contains *Carpinus*, *Pterocarya*, *Alnus*, *Liriodendron*,

Vitis and *Styrax*, and the upper *Picea*, *Tsuga*, *Abies* and *Pinus* The overall emergence of the European aspect of the Tertiary flora took place during the beginning of the Glacial Epoch A few stragglers like *Careya* and *Pterocarya*, however, did occur for sometime during the Pre-glacial.

America

The middle Eocene Green River flora of North America shows a mixture of cycads, palms, and species of *Potamogeton*, *Salix*, *Juglans*, *Hickeria*, *Tilia*, *Alnus*, *Betula*, *Carpinus*, *Sapindus*, *Liriodendron*, *Liquidambar* and *Acer* It seems to have grown at an altitude of about 900 m The Green River formation has been uplifted 1500 to over 3000 m after the flora had been deposited.

The late Eocene Goshen flora of west central Oregon was a mixture of tropical rain forest of the Pacific slope of Panama and temperate rain forest of Costa Rica, and the genera discovered are today distributed far to the south of Oregon

The Chalk Bluffs flora of the same age, known from the north of California, has an assemblage of tropical, sub-tropical and temperate elements Of these, *Chaetoptelea* compares with *C mexicana* of south-western Mexico and Central America It also contains *Cercidiphyllum*, the modern species, *C japonicum*, is found in south-west China and north of Hokkaido in Japan The Eocene flora of Yellowstone Park area is again a mixture of warm temperate forms such as *Pinus*, *Sequoia*, *Platanus*, *Magnolia*, *Juglans* and *Cercidiphyllum*, and the sub-tropical forms like *Persea*, *Ficus*, *Columbia* and *Laurus* The Park is today covered by pine woods with a few species of *Populus* and *Betula*, and *Amelanchier alnifolia*

One of the dominant elements in the Oligocene flora from the beds of the high Rockies to the west of Colorado Springs is *Zelkova*, an Asiatic genus Several other members of the flora are today confined to Asia, such as *Ailanthus* (Simaroubaceae) and *Koelreuteria* (Sapindaceae) Many of the living counterparts of this flora today occur in south-western United States and parts of Mexico

The tropical element at the latitude of Oregon largely disappeared by the upper Oligocene The Bridge Creek flora of the John Day Basin indicates a cooler climate and it compares with the modern Redwood forest *Platanus*, *Juglans* and *Celtis* are not represented in the Redwoods and are found in the west, and *Fagus*, *Carpinus*, *Ulmus* and *Tilia* are not found today in the western North America

During the Miocene, two distinct floras existed, the Arcto-Tertiary flora of the northern Great Basin and Columbia Plateau, comprised by temperate hardwood, deciduous, and conifer forests, and the Madro-Tertiary flora by the semi-arid, Live Oak woodland and thorn forests, extending from southern California into Mexico Amongst the dominants, both had comparable members now found in southern United States and

eastern North America The Miocene Tehachapi flora, known from the White Ash beds in California, has 65 per cent comparable living forms in Mexico

During the early Pliocene, aridity increased considerably in the Great Basin area due to the extensive uplift of the Cascade-Sierra Nevada mountain range and the xerophytic elements of northern Mexico extended northward. The Wieser flora from southwestern Idaho was more temperate and xeric than the early Tertiary flora By later Pliocene times the vegetation assumed the recent complexion

India

In India, the evidences of Tertiary plant life have been found from the Eocene to the Pliocene, but have been worked out from some horizons only Pl 64 shows an Eocene landscape in the Deccan trap area From the Intertrappean beds in central India, ranging in age from the upper Cretaceous to the Eocene, a large and varied flora has been discovered Fossil plants are unevenly distributed in various exposures of the beds, and rich assemblage is seen in Mohgaon Kalan, Sausar and Rajahmundry Fossil woods are strewn all over in varying proportions The flora includes all the groups of the plant kingdom, 112 different forms have been recognized which are referable to 48 genera and 92 species

The plant formation as unearthed from the Intertrappeans abounds in aquatic, marshy and estuarine plants Algae are represented by several species of *Chara*, *Holosporella siamensis*, species of *Neomeris*, *Terquemella*, *Acicularia Acetabularia*, *Dissocladella*, etc Some remains of fungal fruit bodies and spores have also been described Bryophytes are represented by sporogonia

Salvinia intertrappea, *Rodeites dakshinii* and *Azolla intertrappea* are the only members of Filicales *Salvinia intertrappea* compares most closely with *S auriculata* which grows in Brazil and Cuba today *Rodeites* is closely related to *Regnellidium* which also occurs in Brazil

A cycadean ovule (*Gymnovulites*), several conifer cones such as *Indostrobus bifidolepis*, *Takliostrobus alatus*, *Pityostrobus crassitesta* and *Mohgaostrobus sahnii* and several woods belonging to *Dadoxylon*, *Cupressinoxylon* and *Spiroxylon* comprise the gymnospermous constituent in the flora The gymnosperms show podocarpinean, araucarian and abietinean affinities but the cones are very much different from those of the known extinct or extant conifers The presence of gymnosperms is also substantiated by the occurrence of winged pollen

Stems and flowers of *Carex lacustris*, floral axis of Juncaginaceae, *Sparganium*, fruits of *Nypa* and *Tricoccites*, fruits, stems and roots of several palms, *Musa* and *Cyclanthodendron*, seeds, fruits and woods of several dicotyledons such as *Artabotrys odoratissima*,

Xalinospriomites, Faboidea, Cassia, Hedysareae, Viracarpon, Enigmacarpon and *Dryoxylon*, woods belonging to the genera *Euphorbia, Glochidian, Simarouba, Leea, Elaeocarpus, Grewia* and *Aeschynomene*, leaves of *Lagerstroemia*, leaflets of *Acacia*, and flowers of *Salmanthus* and *Salmipushpam* have been described Spores of ferns and pollen grains of palms, though not yet all identified, have also been recovered

Spores and pollen from Eocene deposits, especially lignites, have been described from Rajasthan and the Salt Range, from the Miocene of Kerala, and from the lower Oligocene to the Pliocene of Assam, but no proper identifications have been made Ferns, on the whole, are poorly represented in Rajasthan than elsewhere, and there are indications of the presence of *Nothofagus* in Assam

Amongst fern spores, Schizaeaceae and Parkeriaceae are well represented in the Eocene–Miocene of India The pollen content in the Miocene–Pliocene sediments, especially in Assam, abounds in conifer pollen Pollen grains looking like those of temperate genera such as *Betula Engelhardtia, Corylus* and *Carpinus*, in the Eocene–Miocene deposits of India, are quite interesting

Plant life during the Oligocene to the lower Miocene in the vicinity of Cuddalore consisted of palms, podocarps *(Mesembrioxylon), Mangifera, Shorea, Albizzia, Cassia, Dalbergia, Garcinia* and *Sonneratia* During the Miocene, at the foothills of the Himalayas at Kasauli, members of Guttiferae, Leguminosae and Palmae existed. Wood remains of Dipterocarpaceae (*Anisoptera*), and leaves referable to *Ziziphus, Lagerstroemia* and *Smilax*, and fruits of *Dalbergia* have been found near Jawalamukhi

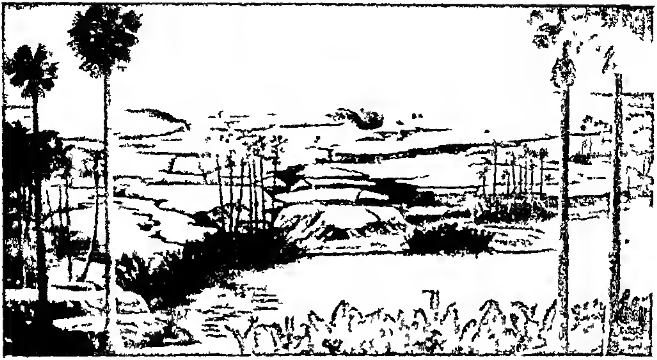
Eocene flora of Assam contained *Trema, Grewia, Nelumbium, Eriadendron, Neolitsea* and *Nypa sahnii* and woods of *Cynometra, Kayea, Gluta, Terminalia, Sharea* and *Dipterocarpus*, and of Jodhpur, members of Guttiferae (*Mesua, Garcinia* and *Calophyllum*) and *Cocas sahnii*

Some of the Tertiary plant fossils from India are shown in Pl 65

Eocene marine algae comprising Corallinaceae and Dasycladaceae are known from Assam *Triploporella* (Dasycladaceae) is known from Ranikot beds in Sind. In the Samana Range of the Ranikot Series, *Lithophyllum, Archaeolithothamnium* and *Mesophyllum*, all members of Corallinaceae, have been found The Eocene beds of the Salt Range have yielded such algae as *Dissocladella, Acicularia, Neomeris, Diplopora* and *Oligaporella* which are found elsewhere in the Triassic Several of the Charophyta and diatoms comprised the other algal forms during the Tertiary

Evolutionary Trends

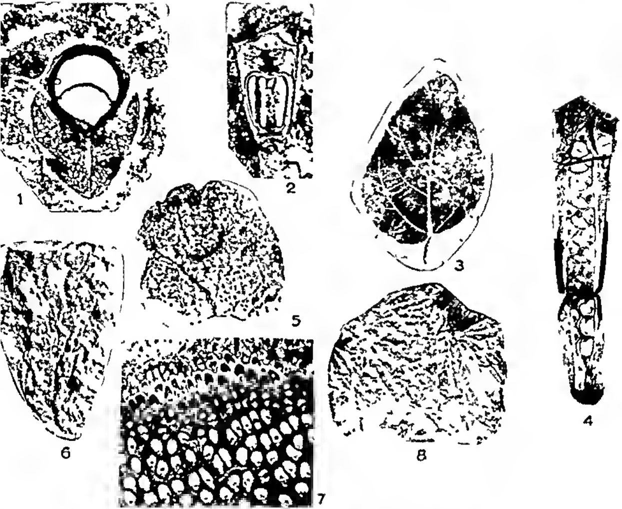
In contrast to the Mesozoic and the Palaeozoic Eras, which saw the emergence of new forms of life, very different from the pre-existing ones, the Cenozoic plant life was



Co r y B bal Sal I stu e of Palaeobo a y Lu kno

AN EOCENE LANDSCAPE IN THE DECCAN TRAP AREA

Due to volcan c eruptions enormous quantities of lava were poured out in the Eocene in Deccan On cool ng it formed the Deccan traps The plants shown are coconut in the background and Nypa in tl e foreground Vegetat on cons sted of the palms and the other ang osperms



Courtesy Birbal Sahni Institute of Palaeobotany, Lucknow

SOME TERTIARY PLANT FOSSILS FROM INDIA

1 *Azolla intertrappea* Sahni & Rao 2 *Sahnipushpam shuklai* Varma syn *S. glandulosum* Prakash vertical section of a flower 3 *Grewia fossil* Lakhanpal 4 *Musa cardiosperma* Jain 5, *Palmoxylon arcotense* Ramanujam, 6, *Neolitsea sahnii* Lakhanpal 7 *Palmoxylon surangei* Lakhanpal, 8, *Nelumbium* sp

devoid of any such new forms Prior to the commencement of the upper Cretaceous, ferns and gymnosperms dominated the plant world This aspect of vegetation was fundamentally changed in the Cenozoic, during which the angiosperms became dominant over ferns and gymnosperms The modernization of the flora that had commenced during the Triassic had finally been completed towards the close of the Tertiary In north-west Europe, for instance, the lower Eocene London Clay flora reveals 2 per cent of modern genera and the upper Eocene Hordle beds flora has 23 per cent The number of modern genera rises to 34 per cent in lower Oligocene, 53 per cent in upper Pliocene (Reuver) and 78 per cent in middle Pliocene (Teglian)

An interesting aspect of Tertiary plant life is the paucity of non-arboreal forms in the older floras Their number increased in the late Tertiary times In tropical forests of today, the herbaceous elements have a subordinate position in contrast to their widespread occurrence in the temperate countries The change of climate from warm to cold and of the pattern of vegetation from the tropical to the temperate during the Tertiary, might have given rise to most of the herbs among angiosperms The changing geographical patterns of flora have already been mentioned The entire Tertiary Period is characterized by the floristic migrations in response to climatic changes There is thus a great contrast between the early and late Tertiary floras In the first half of the Tertiary Period, the vegetation of the Northern Hemisphere resembled that of warmer countries in the Far East and the southern part of North America In the second half of the Tertiary Period, the plant life had relics of temperate species which became associated with arctic forms Intermediate types of floras occurred between the first and the second halves of the Tertiary Period.

CHAPTER SIXTEEN

THE TERTIARY PERIOD — III

Animal Life

The Age of Mammals

Though many kinds of invertebrate animals entered the Tertiary from the Cretaceous, a significant feature of the Tertiary fauna is the total absence in it of the ammonites that ruled the Mesozoic seas for more than 200 million years

Foraminifers. These underwent extensive evolutionary changes along several distinct lines from common ancestors. Their protective testa are found in enormous numbers forming major constituents of some Tertiary rocks These are amongst the most useful Tertiary fossils for correlating marine sediments and are of immense practical value to the oil geologist

Corals. These animals advanced to types in which the walls of the corallites became perforated with holes producing a network pattern Such corals are now abundant in the modern reefs in which the colonies are varied and beautiful

Brachiopods. These had their peak of development in the Palaeozoic and became insignificant during the Tertiary and only a few survive today

Crustaceans The crustaceans became well established during this period. In oil drilling, the fossil ostracods are valuable for correlation of rocks

Echinoderms. These were represented by crinoids, echinoids and sea-urchins The crinoids were stemless and mainly free-swimming forms The echinoids were particularly prolific, and reached their maximum stage of development

Molluscs. The ammonites were replaced by the other members of the phylum, Mollusca, the lamellibranchs and the gastropods, which survived by modifying their structure to suit the new environment They are marine, fresh water and land animals and became abundant in the Tertiary and now hold a prominent place amongst the living animals They are commonly seen along the sea beaches, though some live in subterranean

waters and on mountains at high altitudes Because of the range of beauty of the shell forms as well as of colours, they have attracted the attention of man from time immemorial Lamellibranch shells have been used as tools and utensils in pre-historic cultures The cowry, a name applied to the shells of the gastropod genus, *Cypraea*, was an object of veneration as well as a medium of currency in the past Conches served as drinking cups and trumpets, while the *Strombus* shell is still used as a musical instrument in Polynesia

Fishes With their remarkable evolutionary development, the teleosts or the bony fishes, since the early Tertiary Period, have assumed a prominent position, almost equal to that of the mammals and birds among the vertebrates They include most of our best known fishes, such as the salmon, herring, sole, perch, etc In the array of adaptations of form and habit, they compare with the birds and flowers What is less known about the teleosts is their climbing ability The climbing perch of India can move about on land and, if need be, climbs trees with its spines on the gill-covers and ventral fins Sharks were also quite abundant and some of them were upto 25 m in length The Eocene Green River Beds in Wyoming and Colorado are believed to contain the best known fossil fish fauna

Amphibians. They were numerous in species though limited in genera, and closely related to the present day forms, such as frogs and toads

Reptiles. The reptiles were greatly reduced in numbers and forms Those which persisted included lizards, snakes, crocodiles, and turtles Like frogs and toads they also had as successful a career in the Tertiary as they are having now, but the crocodiles and turtles were not of so many kinds as lizards and snakes Land turtles grew to a large size and the alligators were more numerous than they are now

Birds. During the Tertiary, the birds evolved as the dominant animals of the air and developed structures adapted for life both on land and in air

Mammals

The Tertiary has been called the "Age of Mammals" because of the great abundance of the fossils of mammals A vast number of types, many of which are entirely unknown today, has been discovered Mammals gained their supremacy for various reasons, the most important of which is gradual development of brain, enabling them to retain impressions and to think independently and act intelligently This was probably correlated with the earlier reptile-like mammals in the late Palaeozoic Era, giving up the habit of laying eggs and bringing forth the young ones The females developed milk-producing organs or mammae After birth, the young were reared in a pouch in the

mother's abdomen till they grew strong enough to be let out The kangaroo, opossum, etc are the modern representatives of such mammals called marsupials They were succeeded by the placental mammals which nourish the developing embryo in the womb instead of in the pouch, to this group belong most of the dominant living mammals A number of primitive mammals or living fossils are found in different parts of the world, specially in Australia and South America Some of these are shown in Pl 66

The gulf between the mammal-like reptiles and mammals has been bridged by a miscellaneous collection of such hard parts as skulls, teeth, etc The teeth, being the hardest parts of the body, are most commonly preserved as fossils Their shape and size are dependent on the feeding habits of the animals concerned In Amphibia and fishes the teeth are small, conical and numerous In reptiles, they were conical but large and less numerous In early mammal-like reptiles, they were simple and sharply conical, but of various sizes In later mammal-like reptiles, the teeth began to be arranged in groups—incisors in front for nibbling behind them canines for piercing, and behind canines were cheek-teeth for grinding In some animals, the crowns carried three sharp cusps In one group of mammal-like reptiles, called the therapsids, from the Triassic, the teeth were like those of a pig Therapsids fall into two groups One group was herbivorous In the other group which was carnivorous, the teeth were highly differentiated and the animals had dog-like skulls and they are believed to be the ancestors of mammals The carnivorous group lived on the plant-eating therapsids The therapsids were small animals In the Triassic, only three distinct orders of mammals have been known so far, but by the late Jurassic time the number of distinct orders rose to five

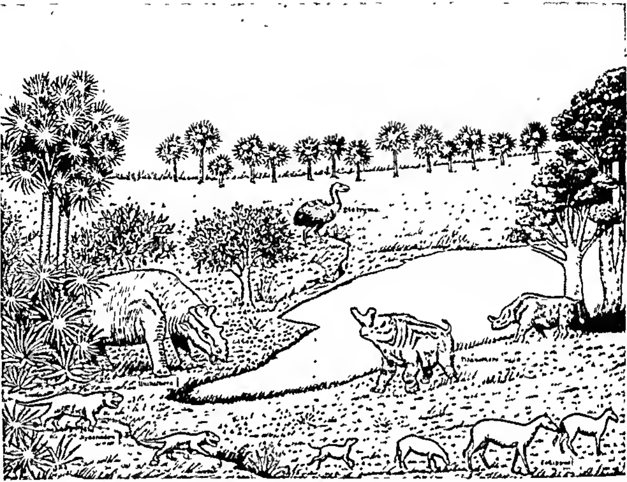
Of the five orders of mammals, represented in the Jurassic and Cretaceous deposits, only one, the Multituberculata rodent-like in appearance and teeth with numerous cusps, survived into the Tertiary The remaining orders did not survive the Cretaceous, but one of them the Pantotheria before extinction, gave rise to the Marsupialia and Placentalia The molar teeth of the pantotheres were triangular in outline with cusps that were also arranged in a triangular pattern The molars of the upper and lower jaws were so arranged that their apices would provide a complex shearing and grinding mechanism when the jaws were closed Because such a functional arrangement of molars is found in some primitive mammals of later age, the pantotheres are considered by some as the ancestors of the Marsupialia and Placentalia

Paleocene–Eocene Fauna

Among the numerous invertebrates the nummulites, now called camerinids, of the order Foraminifera, held a place of prominence Unlike the corals, echinoids, and molluscs,

A GROUP OF PRIMITIVE MAMMALS

Echidna, Glyptodon and Kangaroo are from Australia Echidna and Platypus lay eggs like reptiles, but have a hairy covering like mammals The young ones of Kangaroo are prematurely born and are protected in a pouch by the mother The Glyptodon and Scaly Ant-eater have a scaly covering like reptiles



AN EOCENE LANDSCAPE OF NORTH AMERICA

In the background are palms. Unitathere and Titanothere were giant mammals. The ancestor of the horse, Eohippus, is shown on the right. A variety of Hyaenodon, ancestor of the hyaenas, is also shown. In the background is a giant Kiwi-like cursorial bird, Diatryma

which showed Cretaceous affinities, the nummulites and the operculines appeared rather abruptly in the Paleocene Their small size, rapid evolution and abundance, have made them suitable as guide fossils for correlation They were abundant in the Tethys Sea which at this time covered the Mediterranean and adjacent parts of southern Europe and parts of northern Europe, the Middle East, Pakistan, India, Burma and Indonesia They grew so profusely on the bottom of the shallow seas that their shells contributed to the formation of immense limestone deposits known as nummulitic limestones The present occurrence of these limestones at some of the high elevations on the earth, as in the Himalayas, indicates the great changes that the earth's surface has undergone since they lived The sphinx and the pyramids of Egypt are built of this nummulitic limestone.

Most other invertebrates were almost similar to the modern forms in appearance They include simple hexacorals and some compound forms Echinoderms were represented by crinoids starfishes and sea-urchins Crabs were dominant among the larger crustaceans Bivalved molluscs, such as *Ostrea, Mytilus, Cardium* and *Pecten* and the gastropods, such as *Cypraea, Turritella, Cerithium, Murex, Voluta* etc were also present The Paris Basin in France has become a classic locality for the study of molluscan and other fossils

Among the reptiles, the crocodiles and turtles were common in lakes and rivers as they are now Fishes were chiefly bony and with a few exceptions resembled the present day forms

On land, toothed birds were no more to be seen They died out in the Cretaceous, but an equally strange bird, massive ostrich-like in appearance and standing over two metres high, called *Diatryma*, lived in North America during the Eocene It is shown in Pl 67 Its wings were too small for flight and it roamed in the Eocene glades feeding on plants and small animals

The Paleocene mammals cannot be structurally considered to be the forerunners of modern mammals They are considered archaic, with teeth feet and skulls more like those of reptiles Most of these were marsupial multituberculates, rodent-like, and with low-crowned teeth Some new and progressive forms, ancestors of modern families also evolved during the early Eocene and the multituberculates became extinct Among the placental mammals that developed distinguishable features during the Eocene were the carnivores and hoofed mammals, the ungulates The oldest extinct ungulates appeared in the Paleocene They were of small size and their ancestry was not far removed from that of the insectivores The ungulates assumed modern aspect in the Eocene One of the best amongst them is *Phenacodus* of Wyoming in the USA It was of the size of a fox or sheep, had long head and tail, and five-toed feet that bore small hoofs Its molar teeth were adapted for eating plants An unusual evolutionary

trend in size led to the development of a form like that of a pigmy hippopotamus, with a long body, short legs, and five-toed feet like those of an elephant. Such animals reached their highest development in middle Eocene, in *Uintatherium*, which stood 1.5 m. high and was as heavy as a modern rhinoceros (Pl. 67). It was distinguished by three pairs of horn-like structures on its head and greatly enlarged upper canines. The flesh-eaters known as creodonts, meaning blunt-toothed, were poorly built compared with the modern creatures. However, there were dog-like, cat-like and hyaena-like creatures living on contemporary plant-eaters.

The odd-toed herbivores, perissodactyls, appeared in the Eocene, represented by the earliest ancestral horse, *Hyracotherium*, better known as *Eohippus* (Pl. 68). Its size varied from that of a cat to that of a fox. It had four toes on the front feet and three on the hind feet. The teeth had rounded cusps adapted for grinding; the premolars were not developed for grazing but were adapted for browsing. Probably the animal lived in the forest. Rhinoceroses also appeared in the Eocene. They were slightly larger than *Eohippus* and had four toes on front and three on hind feet. They were browsers, with low-crowned teeth. Their legs were long, adapted for running. The titanotheres or giant beasts were a characteristic group of animals of North America during the Tertiary Period (Pl. 67). They had a heavy body and were distantly related to the rhinoceroses. Their ancestral form, found in the Eocene, resembled tapir, and was about the size of a sheep. The even-toed hoofed animals, the artiodactyls, were the ancestors of camels, deer and pigs. They were small in size, though very much resembling the modern forms.

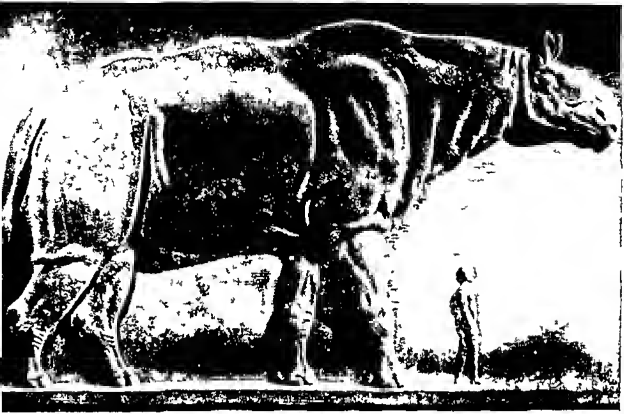
The earliest proboscideans, the elephants and their relatives, appeared in the upper Eocene of Egypt and are known as moeritheriums. They were about the size of a small modern elephant but had larger heads and shorter trunks. The grinding teeth were low-crowned, but the presence of four incisors showed that the growth of tusks had begun.

The earliest known primate was a small lemur-like animal found in the Paleocene of Wyoming. During Eocene several lemur-like forms were also present. One, fairly common in North America, has been named *Notharctus*. It was like the present day lemurs, small, with a long tail and a short face. Another group, the tarsiers, was found in the Eocene of Europe and North America. They were of the size of rats and had wide eyes. The tarsiers are now confined to the jungles of Indonesia and the Philippines.

In India, Pakistan and Burma, as in other countries, Paleocene and Eocene include the bulk of nummulitic limestones. These rocks are best developed in Sind where Paleocene is represented by the Ranikot Series, named after Ranikot Fort in the Laki range, and Eocene by the Laki and Kirthar Series. The Ranikot includes a lower division of fluviatile sandstones and shales, with deposits of gypsum and lignitic coal and an upper division of fossiliferous marine limestones and shales.

Painting Charles R. Knight Courtesy American Museum of Natural History New York

EOHIPPUS, FOUR-TOED HORSE FROM THE EOCENE OF USA



Pa t ng J H Hope Courtesy An er can M iseun of Natt ral History, New York

CAST OF LOW RELIEF MODEL OF BALUCHITHERIUM FROM BUGTI HILLS, BALUCHISTAN

A large oyster, *Ostrea talpur*, has been described from the lower division The upper division has a large molluscan fauna, of which strombid genus *Calyptraphorus* has a wide distribution, having been first described from the Paleocene of Alabama, USA *Campanile*, a cerithid, well known in the Danian of Iran, is another form linking Europe with south Asia The following have also been found *Nummulites nuttalli*, *Lepidocyclina punjabensis*, *Miscellanea miscella* and *Assilina ranikotensis*, echinoids *Cidaris vernenili*, *Schizaster alveolatus* and *Salenia blanfordi*, gastropods *Ampullina polybathra*, *Calyptraphorus indicus*, *Rimella fusoides* and *Natica adela*, cephalopods *Styracotheutis orientalis*, the last surviving belemnite, and *Belosepia incurvata*, a link between belemnite and modern cuttlefish

The Laki Series (lower Eocene), which is also developed in Baluchistan, contains many Ranikot foraminifers including *Nummulites atacicus* and *Assilina granulosa*, but is distinguished by the presence of two new genera of echinoids, *Amblypygus* and *Brissopsis*, as well as the molluscan genera, *Vicarya*, *Vicetia* and *Cordiopsis*, and *Gisortia murchisoni*

The middle and upper Eocene are represented by the Kirthar (Khirthar) Series, named after the most important range in western Sind The series has a different nummulitic fauna from that of the Laki containing *Nummulites atacicus*, *N complanatus*, *N laevigatus* and *Assilina spira* A worldwide lamellibranch, *Ostrea multicostata*, recorded from Europe, North Africa, Turkistan and Jamaica, occurs in this series, along with gastropod, *Velates perversus*, while the foraminifer, *Dictyoconoides cooki*, is abundant

Both Laki and Kirthar Series are represented in Gujarat and western Rajasthan, the Himalayan foothills, and in the southern flank of the Pir Panjal in Kashmir In Assam, the Eocene is represented by the Jaintia Series in the southern and eastern parts of the Shillong plateau where foraminifers indicate the full Ranikot-Laki-Kirthar sequence *Nummulites atacicus* and *N beaumonti*, together with *Calyptraphorus indicus*, etc occur in the Eocene of Burma

The vertebrate fauna of the upper Eocene of Burma shows an extraordinary predominance of anthracotheres which form about 95 per cent of the total and constitute the most primitive types so far known Burma is thought to be the original home of this group The other elements of the fauna, titanotheres, tapiroids, and the aquatic rhinoceros, indicate migration from North America

Oligocene Fauna

The larger foraminifers such as *Nummulites* and *Lepidocyclina*, continued to flourish in the open seas A characteristic species was *Nummulites intermedius* Reef-building corals were common in tropical seas as also the molluscs and in increasing numbers Echinoids were commonly represented by *Eupatagus* and *Clypeaster* Insects, due to their fragile nature, are not found as fossils in proportion to their abundance, but in the neighbour-

hood of Konigsberg in Germany and at a few places in USA, the resin from the Oligocene, pines contains countless unwary insects belonging to most of the modern orders

The mammals were now nearer to modern forms There was a diminution of the browsing and increase in the grazing types, probably an indication of extensive grass-lands There were rodents, hares, monkeys, civets, mongooses, pigs, etc.

The titanotheres which grew from the size of a sheep in Eocene to that of a good-sized modern rhinoceros by the middle Oligocene, were the brontotheres Titanotheres died out in early Oligocene *Baluchitherium*, a near relative of rhinoceros, grew to an enormous size and was one of the largest land mammals that ever lived (Pl. 69) It was a hornless rhinoceros that lived in late Oligocene and early Miocene It was over 10 m from head to tail, and stood about 5 5 m high at the shoulder When originally discovered in 1911 from a few bone pieces from Bugti beds of Baluchistan in Pakistan, it was thought to be a rhinoceros larger than any known elephant, and the discoverer hoped that more bones would be found This hope was fulfilled by the discovery of three partial skeletons in Mongolia

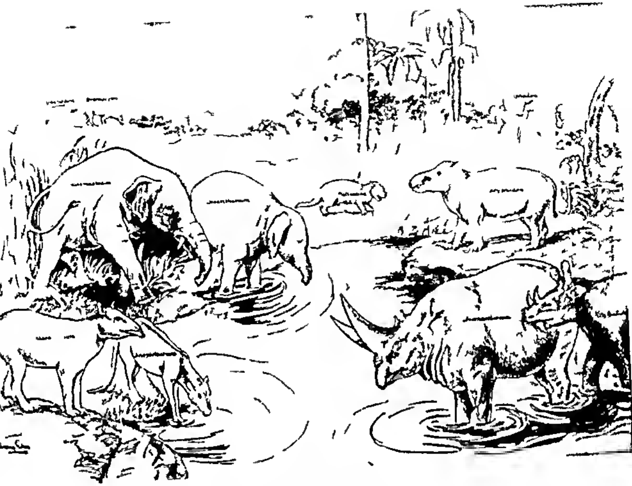
A descendant of *Epihippus* was *Mesohippus*, a three-toed horse of Oligocene from South Dakota in USA It was about one metre long and half a metre high Its premolars and the molars were similar and well adapted for crushing and grinding vegetation. The middle toe of each foot was the largest and all the three had usable hoofs

From *Moeritherium* of Eocene in Egypt, one line of development led to the dinotheres with recurved lower tusks, and another line gave rise to elephants and mastodons Mastodons appeared in the lower Oligocene of Egypt and resembled the modern elephants in appearance but had different type of teeth, their second upper incisors were enlarged into tusks extending forward and downward The lower jaw was long and had two tusks extending forward

Among the primates, the earliest ape, *Propliopithecus*, was discovered in the lower Oligocene in Egypt

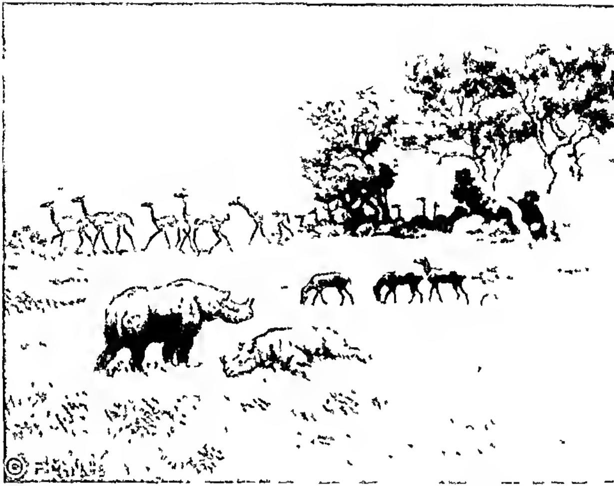
Plate 70 shows an Oligocene landscape with prominent mammals of the time

The Oligocene is unrepresented in the Himalayan region, as during this time exposed rocks were undergoing erosion It is in Baluchistan and Sind in Pakistan, and in Gujarat, western Rajasthan and Assam as well as in Burma that marine fossiliferous Oligocene deposits are found In Sind and adjacent parts of Baluchistan, the Oligocene is known as the Nari Series The name is derived from the Nari Nai, a river in Sind along the banks of which a section of the series is well exposed. The Nari Series is characterized by an abundance of *Lepidocyclina* (*Eulepidina*) *dilatata* It is a European



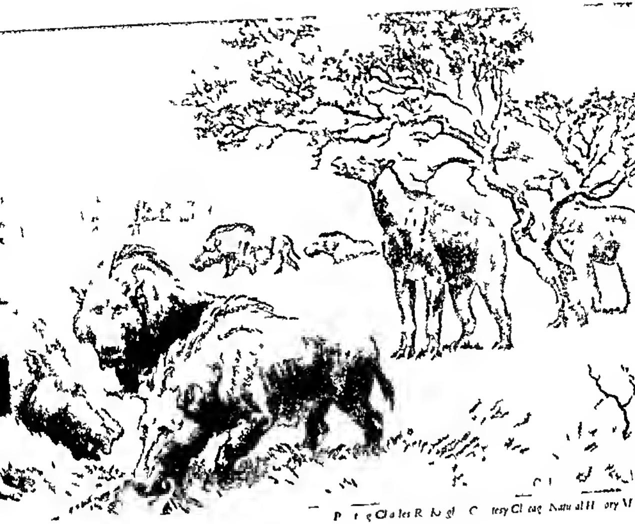
AN OLIGOCENE LANDSCAPE

The animals shown are primitive elephants, tapirs, members of the rhinoceros family and ancestors of dogs and hyaenas



RESTORATION OF A M

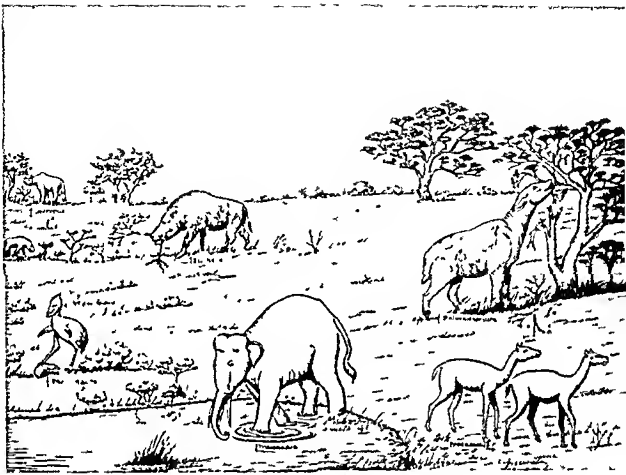
Giant hogs at lower right two-horned rhinoceroses



P t g Cla les R Ja gl C tesy Cl cag Natu al H ory M

NDSCAPE IN NEBRASKA USA

camels at m ddle left and l orses to left of m iddle



ANIMAL LIFE IN MIOCENE PERIOD

Baluchitherium is grazing on the top of a tree to the right is Procamelus, ancestor of camels, in the foreground is the extinct elephant, Trilophodon, to the left is a giant bird, Phororhacos, and in the background is Moropus

Oligocene form and is also found with *Nummulites intermedius* in the lower Asmari limestone of Iran. Some characteristic Nari forms include, coral: *Montlivaltia vignei* and echinoids *Cidaris verneuili*, *Coelopleurus forbesi*, *Clypeaster profundus*, *Temnechinus rousseaui* and *Moira primaeva*. The Nari fauna in Sind appears to be essentially a development of genera already present in the area. Some of the forms now living in the Indian Ocean can be traced back to species which first appeared in the Nari beds. Thus the gastropod, *Turbinella episoma* of the Oligocene of Sind and Baluchistan is very close to *T. fusus*, now found in the Andaman seas, *Terebra narica* is an ancestral form of the living *T. crenulata*, and *Harpa narica* seems to be intermediate between the Ranikot species *H. morgani* and the living *H. conoidalis*, of which it may be a forerunner.

Miocene Fauna

The marine faunas of the Miocene in different regions appear to be the forerunners of the modern faunas of those particular regions.

Nummulites died out, but other larger foraminifers took their place. Molluscs were common. Among the important forms were *Pecten*, *Ostrea*, *Aturia*, *Cardita*, *Spondylus*, *Ancillaria*, *Pleurotoma*, *Trochus*, etc. Of the echinoids, *Clypeaster*, *Scutella* and *Echinolampas* were especially abundant.

Bony fishes occurred in various forms.

All the modern carnivores appeared by the Miocene time and started hunting in the open landscape. The dog and true cats evolved towards the close of the epoch. From the dogs, other new types branched off including the bear which fell back to an omnivorous diet. The cats were perfect carnivores. In them, the teeth that had little use were reduced in size, but the carnassials, in which two or three cusps grow into long cutting points, and the canines, were highly developed. Extensive grasslands led to rapid development of horses. For feeding on grass, there was a progressive increase in the ridge-like cusps in their teeth. Being defenceless against the carnivores, they developed speed on hard open grasslands, with single toe and slender leg bones, fusion of tibia and tarsus, and finally, light body such as found in *Merychippus* of the late Miocene.

Various lines of one- and two-horned rhinoceroses evolved. The *Baluchitherium* became extinct but *Diceratherium* was abundant in Nebraska, USA (Pl 71). It had two small horns, side by side, on the nose.

In this epoch also arrived the *Dinotherium*, an ancestral elephant with two tusks in the lower jaw curving downwards. These were perhaps used for raking up roots. There were no tusks in the upper jaw and the molar teeth were provided with two crests which showed little change throughout their long history. The *Trilophodon*, formerly known as *Tetrabelodon*, came with the dinotheres. It had four tusks, two in the lower jaw and

two in the upper jaw, an elongated snout, and an almost horizontal trunk The molar teeth were strongly cross-crested, unlike the large cones of the *Mastodon* The *Mastodon*, in the Miocene, had a parallel development with the long-jawed *Trilophodon* It had teeth with separate roots and blunt crests, two tusks on the upper jaw, but the lower tusks were either wanting or remained as traces Body was coated with rusty brown hair, height was about two metres in the case of females and up to three metres in males, each foot had five toes It lived beyond the Ice Age Because of its abundance as fossils and wide distribution, it is the best known fossil mammal

The *Moropus*, the largest of chalicotheres, was perhaps one of the most peculiar odd-toed perissodactyl ever known It was discovered in the Agate Springs Bone Bed, Nebraska, USA It had a horse-like head, thick body, thick forelegs like those of a rhinoceros, and hindlegs like those of a bear It had claws instead of hoofs for digging out roots and bulbs from the ground. Animal life in the Miocene is shown in Pl 72

The ruminants like the sheep, goats, musk oxen, antelopes and cattle, appeared for the first time as also the giraffes which were closely related to the deer They had short necks similar to that of okapi of Congo

The lower Miocene adjoining the Arabian Sea in Sind and western India is known as Gaj Series In Kutch it is conformable with the Oligocene in one area, but elsewhere in the coastal parts of Gujarat it transgresses on middle Eocene or Deccan traps In Kerala, Miocene is found near Quilon, in Assam it is exposed in the Surma valley, and in Burma in the Pegu Yoma Many Miocene fossils have their living allies, while some are the forerunners of living forms The Gaj rocks are often found crowded with large Lepidocyclines accompanied by *Operculina*, *Rotalia* and other foraminifers The Mediterranean forms like *Ostrea virleti*, *O latimarginata*, *O gryphoides*, etc. are very similar to those described from the Indo-Pacific region, but the proportion of molluscan forms comparable with Indo-Pacific forms is much smaller in the Miocene than in the Oligocene. The window-pane oyster, *Indoplacuna*, found in the Gaj beds associated with modern *Placuna*, is a descendant of the Eocene *Carolia* which in turn is a derivative of an unnamed species of *Anomia* from the Kirthar *Placenta lamellata* Dey from the Miocene of Quilon is the connecting link between *Indoplacuna* and *Placenta*

Some characteristic lower Miocene fossils of India, Pakistan and Burma are the echinoids *Breynia carinata* and *Echinolampas jacquemonti*, the gastropod *Turritella angulata*, foraminifers *Lepidocyclina tournoueri* and *L sumatrensis*, and the lamellibranch *Ostrea latimarginata*

The percentage of molluscan forms identical with or allied to those of living species is much higher in the upper Miocene than in the lower Miocene One of the most common oysters of the Miocene is *Ostrea virleti*

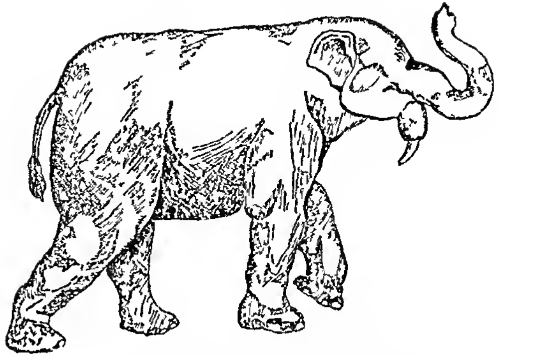


FIG 65 RESTORATION OF *Dinotherium giganteum* A QUEER EXTINCT ELEPHANT WITH INCISORS CURVED INWARD AND DOWNWARD, FOUND IN THE LOWER AND MIDDLE SIWALIKS OF THE PUNJAB

Middle Miocene–Lower Pleistocene Fauna

In India, both *Trilophodon* and *Dinotherium* first appeared in the Kamlial sandstone of the lower Siwaliks

The Kamlial stage in the Potwar or Rawalpindi plateau indicates the advent of fresh and running water conditions in the Punjab for the first time since the withdrawal of the sea of Eocene and Oligocene times and the filling up of the lagoons mainly by the deposits of the Murree Series

From the Kamlial of the Potwar area many mammalian fossils have been collected including *Dinotherium giganteum* (Fig 65), *Trilophodon* and *Chalicotherium*, a hornless, grazing rhinoceros, with a short, massive body like that of a pig It had a three-toed foot and two strong tusk-like incisors in the lower jaw, and seems to have been adapted for steppe land with occasional swamps Higher up, in the Dhok Pathan stage of the middle Siwaliks these are joined by the *Mastodon* and *Stegodon*, which did not survive the upper Miocene In the Kamlials there were also small pig-like animals, called anthracotheres These soon died out giving rise to *Merycopotamus*, the possible ancestor of *Hippopotamus* *Merycopotamus* is found in the middle Siwaliks It was like an anthracothere, but without the fifth cusp in its upper molar The hippopotamus, which became abundant in the

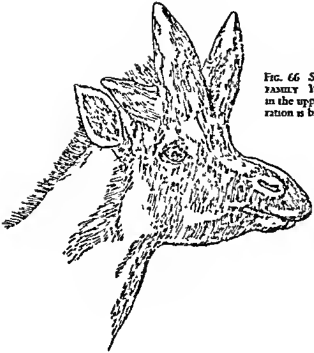


FIG. 66 *Sivatherium giganteum*, AN EXTINCT MEMBER OF THE GIRAFFE FAMILY It is the largest known ruminant living or extinct, found in the upper Siwaliks of northern India and West Pakistan. Restoration is based on fossils collected from near Chandigarh and Kalka, Punjab (After Colbert)

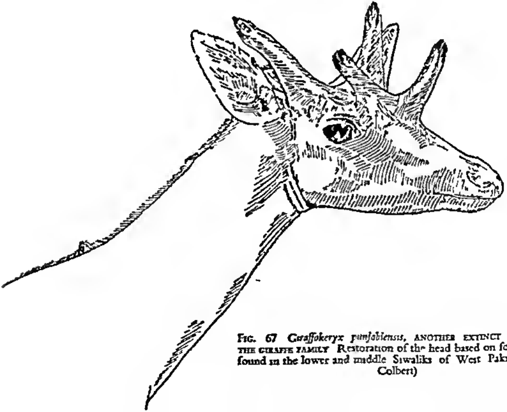


FIG. 67 *Giraffokeryx punjabiensis*, ANOTHER EXTINCT MEMBER OF THE GIRAFFE FAMILY Restoration of the head based on fossil remains found in the lower and middle Siwaliks of West Pakistan (After Colbert)

upper Siwaliks made its first appearance in the Dhok Pathan Giraffe-like animals are also found in the lower Siwaliks They were small animals The first large giraffe, a two-horned animal, appeared in the Nagri beds, the lower division of the middle Siwaliks In higher beds, the Dhok Pathans, occurs a closely related ancestor of the modern African giraffe and the large extinct giraffe, *Sivatherium* (Fig 66) A distinguishing feature in the teeth of the giraffe is the division of the lower canine teeth into two halves by a slit No other living mammal except the okapi in the Congo forests has these peculiar canine slits in the lower jaw which are seen in the *Sivatherium* The antelopes began to flourish in the Chinji times (middle Miocene), but they were all small animals The curved-horned antelopes, and *Hipparion*, an ancestor of the horse, were first found in the Chinji bed and became abundant in succeeding Dhok Pathan beds The *Hipparion* had three toes, but the side ones did not touch the ground No earlier ancestor of horse than *Hipparion* is found in India

The okapi-like *Giraffokeryx*, water deer, is common in the Chinji stage The genus seems to be confined to India and allied to the Chinese Pontian species, *Palaeotragus quadricornis* It may also be a forerunner of the sivatherines of the Pontian and Dhok Pathan (Fig 67)

The modern pig with rare exceptions, has inherited 44 teeth from its remote ancestors, but there are gaps between the front teeth and the canines and between the canines and the cheek teeth The teeth bear separate tubercles which neither coalesce into transverse ridges as in the tapir, nor become crescent-shaped longitudinal ridges as in the grass-eating cattle A curious pig-like creature, named *Listriodon* occurs in the lower and middle Siwaliks The tubercles of its teeth are united to form transverse ridges The ancestors of the African hogs, whose premolars have a tendency to disappear, are also found in the lower and middle Siwaliks These two divisions of the Siwaliks have yielded fossil remains of *Amphicyon*, a near common ancestral stock of both the dog and the bear It is first seen in the Kamlials, while the hyaenas first appear in the Chinji of the lower Siwaliks, as also the sabre-toothed tigers

All modern rhinoceroses are characterized by the reduced number or absence of incisors and have either one horn as in the living Indian rhinoceros, *Rhinoceros unicornis*, or two horns as in the Javanese and African rhinoceroses In the lower and middle Siwaliks are found the remains of an extinct genus of rhinoceroses, *Aceratherium*, which had the same number of front teeth as the living rhinoceroses, but had no horns A species of true rhinoceros appeared for the first time in the Dhok Pathan beds It has been called *Rhinoceros sivalensis* and is believed to be an ancestor of the two-horned Javanese rhinoceros

In the Chinji beds of the Salt Range in Pakistan, many of the genera found in the Kamlial bed, occur associated with more specialized pigs, *Listriodon* and *Sus* The fauna

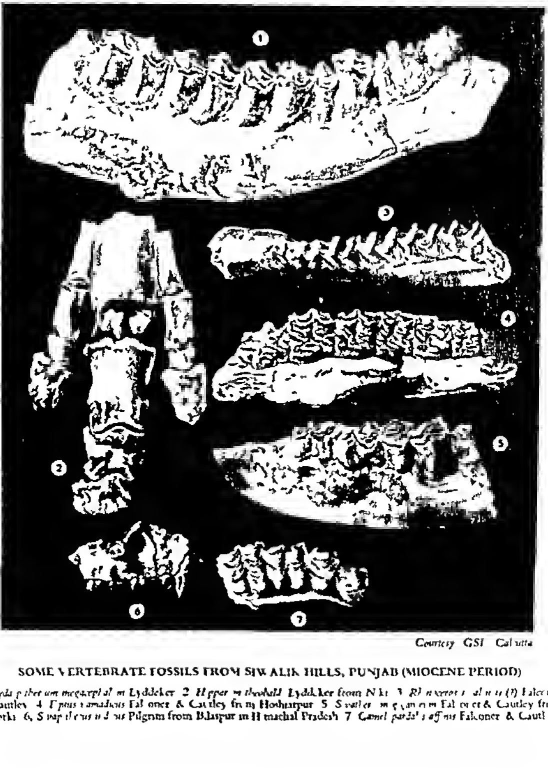
of Nagri (Salt Range) and Perim are also closely allied, but include the large giraffe, *Bramatherium* or *Hydaspitherium* Some of the vertebrate fossils from Siwalik hills, Punjab, are shown in Pl 73.

In the upper Gaj beds, referable to early Miocene of the Bugti hills in eastern Baluchistan, famous for the remains of *Baluchitherium*, the majority of vertebrate fossils are anthracotheres that were also flourishing at the time when the lower Siwaliks (the Kamlials) were being deposited Thus, it seems as if the anthracotheres were the dominant animals of India, Pakistan and Burma during the Eocene–Oligocene–lower Miocene times But in the Kamlial time they were much reduced in number and died out giving rise to a rather specialized descendant, called *Merycopotamus* Associated with the anthracotheres in the Bugti hills are the other ungulates, a few proboscideans, and carnivores Similar mammalian fossils have been recorded in the conglomerate bed at the base of the Murrees (lower Miocene) in the Potwar plateau of West Pakistan

The tiny island of Piram near the Kathiawar coast of Gujarat, has become classic under the name, Perim, because of the discovery there of mammalian fossils in 1836 The fauna is not different from the Dhok Pathan fauna with which it is correlated Among the various forms found are the large giraffoid, *Bramatherium perimense* (Fig 68), and the large antelopes, like *Tragocerus perimensis*, etc

In Pliocene, the mammalian fauna was more diverse than that of today but it was

FIG 68 *Bramatherium perimense* ANOTHER EXTINCT MEMBER OF THE GIRAFFE FAMILY Restoration of the head based on fossil remains found in the middle Siwaliks of West Pakistan and Perim island western India (After Colbert)



Courtesy GSI Calcutta

SOME VERTEBRATE FOSSILS FROM SIWALIK HILLS, PUNJAB (MIOCENE PERIOD)

1 *Hydaspitherium megacephalum* Lydekker 2 *Hipparion theobaldi* Lydekker from Nahan 3 *Rhinoceros palaeindicus* (?) Falconer & Cautley 4 *Equus namadicus* Falconer & Cautley from Hoshiarpur 5 *Sivatherium giganteum* Falconer & Cautley from Roorki 6 *Sivapithecus indicus* Pilgrim from Bilaspur in Himachal Pradesh 7 *Camelopardalis affinis* Falconer & Cautley

Painting by Charles R. Knight Courtesy American Museum of Natural History New York

WESTERN NEBRASKA USA IN THE MIDDLE PLIOCENE

Group of Pliohippus leidyanus on the right Teleoceras in the centre Asiatic antelope in the left foreground Alticamelus in the left background and distance

less varied than that of the Miocene In the early part of the epoch, two evolutionary lines radiated from *Merychippus* One led to the *Hipparion*-type showing a progressive development of the skull and teeth, but little development of the three-toed feet The other showed progressive changes, not only of the skull and the teeth, but also of the feet, which led to the evolution of one-toed horses, as illustrated by the genus *Pliohippus* from which the modern horse evolved in the next epoch *Pliohippus* and other animals of the middle Pliocene are shown in the restoration of the landscape of that time in western Nebraska, USA, reproduced in Pl 74

Rhinoceroses declined, but the modern giraffes evolved from short-necked giraffes like *Sivatherium* and *Samotherium* The *Megatherium*, the giant ground sloth and ancestor of the present day tree sloth of South America, appeared in the southern parts of USA It was about the size of a small elephant, with a short wide head and strong legs

The familiar ruminants, the sheep, goats, etc which first appeared in the Miocene, began to evolve and radiate rapidly in all directions during this epoch The greater part of this evolution was effected in the Old World

The early true elephant appeared in late Pliocene Though mastodons had tusks and long trunks, the true elephant did not evolve from them It descended from *Gomphotherium*, which had teeth like those of mastodons, but relatively short upper jaws and bigger tusks The true elephant, *Elephas*, evolved by the shortening of skull and lower jaw The premolars became small and the molars large In some stegodons, like *Stegodon ganesa* from lower Pliocene of the Siwalik hills, the tusks attained the enormous size of three metres In *Elephas antiquus*, first found in late Pliocene of Europe, the tusks were nearly straight and molar teeth were rather short *Elephas antiquus* attained a gigantic size in India and the crest on its teeth increased by becoming laminated The first result of these changes was in *Stegodon*, that appeared in Asia during early Pliocene but reached Africa during the Pleistocene Among the most uncommon mastodons, was the so-called shovel-tusker, *Amebelodon*, which appeared in North America in this epoch Its lower tusks were flattened instead of being round, and joined together to scoop out plants from the ground. A generalized upper Pliocene landscape is shown in Pl 75 The Pliocene was remarkable for the development of carnivores which thrived and gained supremacy over herbivores due to their greater speed and power of attack The great sabre-toothed tiger had its maximum development in this epoch *Smilodon* spread over North America and migrated to South America by the land bridge that came into existence by the withdrawal of water from the Panama region It was a short-tailed animal, much more heavily built than the modern lions Its canine teeth were knife-like and curved for slashing or stabbing Its legs were not built for running It would await its victims near groves or water spots and then pounce upon them *Elephas antiquus* had its counterpart

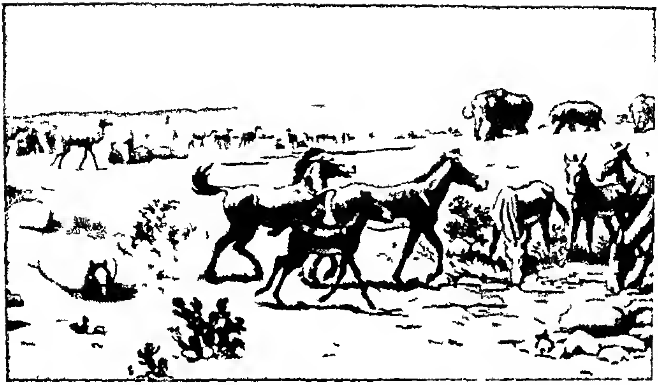
in *Elephas namadicus* which had a peculiar skull due to the development of an overfolded ridge on its frontal Due to the changes that took place at the end of Pliocene and in early Pleistocene, some regions inhabited by *Elephas antiquus* became isolated as islands, where species became dwarfed and specifically distinct from those found elsewhere.

Bos made its first appearance in the upper Pliocene of Val d' Arno, in Tuscany, Italy Like the present day ox, it had two well developed horns. In the ancestral forms, in the upper Miocene, the horns were close together as in the modern antelopes and sheep In the Pliocene, as the forehead broadened, the horns became widely separated from each other The side toes were present but were reduced, shifted behind and did not touch the ground Their reduction in size was for adaptation to the plains and this was accompanied by the corresponding modification of the two remaining toes carrying the "cloven hoof", and fusion of the sole bones into one known as the cannon bone

In India, the Tatrot stage (upper Siwalik), referable to the lower Pliocene, contains some of the genera found in the middle Siwaliks These include *Hipparion*, *Merycopotamus* and *Hippopotamus* *Stegodon* is more common than *Mastodon* Large giraffes developed into the bizarre *Sivatherium*, the largest known ruminant, with a skull measuring over 60 cm in length It had two pairs of bony horns, the hinder pair being much larger than the front one The buffaloes and new types of antelopes and other ruminants are also seen in the Tatrot stage First true elephant, *Elephas planifrons*, and first true ox, *Bos acutifornus*, appeared in the Pinjor beds, which are, therefore, comparable to the upper Pliocene of western Europe Other fossils found in the Pinjor beds include *Stegodon*, *Equus*, *Rhinoceros*, *Merycopotamus*, antelopes, etc A similar assemblage of fossils has been found in Ceylon The Upper Irrawaddy Series of Burma has also yielded species of *Mastodon*, *Stegodon*, *Hippopotamus* and *Bos*, comparable with those found in the Tatrot stage The species of bison, *Bos*, etc in the Pinjor are more primitive than any found elsewhere It is, therefore, reasonable to suppose that India was a centre where excellent opportunities for flourishing of Bovinae were available, and migrations from India were responsible for the oxen and buffaloes of the world The modern fauna of central Africa includes many bovine genera of the Siwalik Series These are evidently immigrants from Asia

The upper Siwalik beds referable to the Pinjor stage, found in the Pabbi hills, Gujarat district West Pakistan, have yielded fossils which include *Stegodon ganesa*, *S insignis*, *Elephas planifrons*, *Sivatherium giganteum*, *Bos acutifrons*, etc

Mammalian fossils were first discovered from the Siwalik hills near Hardwar in 1839 Perhaps the most extraordinary find then was that of bones and portions of the carapace of a giant tortoise, measuring over 6 m in length, in the upper Siwalik, which has been named *Colossochelys atlas* This species has also been recorded from the Tatrot stage of the upper Siwaliks near Chandigarh in Punjab



Painting Charles R Knight Courtesy American Museum of Natural History New York

UPPER PLIOCENE LANDSCAPE

Glyptotherium and *Equus* in the foreground *Stegomastodon arizonae* in the background group of Pliocene stallions mares and foals (left) and group of *Equus* mares and foals (right)

Evolutionary Trends

The Tertiary was above all the "Age of Mammals" and by far the greater part of mammalian evolution took place during this period Of the 15 orders of mammals found in the Paleocene, the first epoch of the Tertiary, only 3 descended from the Cretaceous These were multituberculates, opossum-like marsupials and the shrew-like and hedgehog-like insectivores The remaining 12 orders were placental mammals, which probably evolved from an insectivore stock within an extremely short span of geological time during the passage of the Cretaceous to the Tertiary The conditions for such an explosive evolution were then available The dinosaurs, the enemies of the primitive mammals were all gone There was limitless living space and most generous food supply Some new foods in the form of highly concentrated products of flowering plants, fruits and nuts, or insects feeding on flowering plants were also available, providing better nourishment The mammals, therefore, multiplied, underwent many adaptations, radiated out in every direction and occupied every available habitat There were tree-dwellers, burrowing animals, herbivores, and carnivores In the Eocene, 10 new orders arose and were added to 15 orders derived from the Paleocene The mammalian fauna during early Eocene was thus a complex of archaic, moderately ancient and new types, living together The multituberculates were displaced by the more advanced rodents There were archaic herbivores, e g *Phenacodus*, with teeth adapted for plant eating, but with claws, long tail and short limbs, characteristic of flesh-eating animals There were also early carnivores, known as Creodonta, rather poorly built in comparison with their modern counterparts They had no carnassials, but only molars, capable of crushing food Dog-like, cat-like, and hyaena-like forms were also present Perissodactyls, the toed ungulates, suddenly appeared at the beginning of Eocene and were represented by *Eohippus*, dawn horse, in North America and by *Hyracotherium* in Europe These were very small in size Artiodactyls, the even-toed ungulates, of which pigs, sheep and cattle are typical examples, remained in obscurity during the early Eocene, but spread out vigorously during the late Eocene There were bats in the air and whales in the oceans, but the evolutionary history of these is not definitely known The whales evolved during the Eocene Epoch from the primitive carnivorous land mammals, that entered the oceans presumably using rivers and coastal marshes as stepping stones They reached their maximum development in the new habitat some time between the Miocene and Pliocene Epochs, probably 12 or 13 million years ago Many of them became giant animals exceeding the great dinosaurs in size Several other mammals also took to the sea during the Tertiary These include the sea-cows of the Paleocene, and the seals, sea-lions and walruses, making their first appearance in the Miocene The similarity of the Paleocene fauna of Europe with that of North America suggests land connection between the

two continents Australia, since early Tertiary, harboured a fauna of its own This continent was separated from the rest of the world before the evolution of the higher mammals took place Here, the marsupials, protected against more advanced competitors, evolved independently in many directions playing the role which the placental mammals performed in Eurasia, Africa and North America There grew marsupial herbivores and carnivores, marsupial "squirrels", and so on, a curious fauna which is still seen in that continent

South America likewise became separated from the rest of the world some time after the beginning of the Tertiary This region was then inhabited by various archaic plancentales Shielded from outside competition, a unique fauna evolved there In the Pliocene, North and South America were again connected by the Panama isthmus and immediately there was a southward migration of modern ungulates and carnivores leading to the extermination of most of the endemic South American ungulates Some of them were able to escape from the immigrants, and survived well into the Pleistocene

By the end of the Eocene, archaic mammals were replaced by more advanced species, which were the forerunners of the present day mammals Thus, by the beginning of the Oligocene, mammals began to assume a modern appearance New families of perissodactyls and artiodactyls appeared during the Oligocene, and horses deer, rhinoceroses camels, cats, dogs, etc could now be recognized The creodonts and giant titanotheres became extinct

During the Miocene, there was a general uplift of the continents The northern land masses grew cooler and drier Forests retreated and grasslands expanded, providing much scope for the development of the hoofed animals Uplift of land brought Eurasia and North America into contact across what is now the Bering Strait Africa and Eurasia also became connected, allowing inter-migrations of fauna But not all the mammals found had crossed the available land bridges Thus, the isthmus of Panama, during the Pliocene Epoch, provided a link between North and South America While there was an influx of immigrants from North to South America, the beavers, pronghorn antelopes, etc never moved down from the north, and the monkeys never went all the way along the Panama isthmus from the south The links provided by such isthmus bridges are called "filter bridges" as they act like filters, allowing inter-migrations of some faunal elements but not of others

In the Pliocene Epoch, the land continued to rise, climate also became cold heralding the coming Ice Age of the Pleistocene Warmth-loving mammals migrated to warmer places Although some specialized forms evolved, the growing harsh and uncongenial environment restricted the expansion and diversification of the mammals, so that the inefficient and dull forms began to die out

It will be seen that primitive ungulates, primitive carnivores, early primates (prosimians), insectivores, and multituberculates formed the bulk of the Paleocene and early Eocene faunas The primitive ungulates constituted 15 to 30, primitive carnivores about 20, primates about 10, and insectivores about 10 to 20 per cent of the fauna In the late Eocene and Oligocene, the modern ungulates formed about 50, modern carnivores about 5 to 25, and rodents about 10 to 25 per cent The primitive types were on the verge of extinction The same general pattern continued more or less through the rest of the Tertiary into the Pleistocene when the perissodactyls, artiodactyls and carnivores suffered a great set back Since about the middle of Oligocene, the artiodactyls started expanding while the perissodactyls declined and ultimately both died out in the Pleistocene Since about the middle Oligocene, the rodents have been greatly expanding and today they constitute half of the North American mammalian fauna

No new major groups of marine invertebrates appeared in the Tertiary The evolution of these animals during the Tertiary Period, continued to be on the pattern which their Cretaceous ancestors had exhibited At the beginning of the Tertiary, the tropical seas encircled the world broadly on either side of the equator permitting inter-migration of fauna so that there are many similarities among marine fossils from the opposite sides of the earth. But with the passage of time, the extent of tropical seas became more and more restricted The ocean waters of middle and high latitudes became gradually cooler, and many marine faunas became adapted for cold and even very cold water habitats In the late Tertiary, it became possible to distinguish cold water faunas from warm water ones, though they had a rather different distribution from those of the present day No doubt the foraminifers, modern corals, lamellibranchs and gastropods, the echinoids, and the crustaceans became firmly established in the sea and evolved along diverse lines, the marine invertebrates of the Tertiary Period, at least during its earlier half, might not have been as prolific as during the Cretaceous Period This was because the uplift of the land during the period eliminated the interior seas, thus reducing the living space, while rapid erosion of land mass flooded the continental shelves with silt and mud, making the regions unfavourable for such organisms as sponges, corals, brachiopods, bryozoans, crinoids, and other fixed forms to thrive Since the Tertiary, the modernization of fauna has been going on

The Siwalik fauna is closely similar to that found in the Miocene and Pliocene of southern Europe, northern Africa, central Asia, China, Pakistan, Burma and Malaysia The similarity has been more marked in some epochs than in others Thus, the lower Miocene mammals of India, Pakistan, Burma, Europe and northern Africa are so similar as to indicate free land communications among these regions during that time During the middle Miocene, land communications became restricted and the species showed

independent courses of evolution The anthracotheres became extinct in Europe but persisted in India and Pakistan in *Merycopotamus*, the possible ancestor of *Hippopotamus* During the Pliocene, free communication between Europe, Pakistan, India and China was restored and hordes of mammals that were developing in Asia during the upper Miocene migrated to Europe producing a sudden faunal change there The closer similarity of the Pliocene mammalian fauna of China to that of Europe than that of India is due to the rise of the Himalayas which acted as a barrier, probably climatic, rather than physical *Sivatherium*, which is exclusively of upper Siwalik, seems to have migrated into central Africa in the Pleistocene In India, the Giraffidae were rather numerous in middle Siwalik times, scarce in the upper Siwalik and later became extinct Remains of extinct species of giraffe have been found in Greece, Hungary, Iran, Pakistan India and China, but the family is now exclusively African The Bovidae probably originated in central Asia According to American palaeontologists the *Hipparion* found in the Siwaliks of India, is a migrant from America, but Pilgrim claims that *Hipparion* and *Equus* separately appeared earlier in India than in North America and, therefore, could not be migrants from the latter continent There is little doubt that the Proboscidae originated in Africa, but the genera *Stegodon* and *Elephas* originated in India The anthropoid apes are represented in such a variety in India that the original centre of distribution of the group could not have been far away from northern India They possibly came from the west through Egypt and Arabia From the entire Siwaliks, over 80 specimens have been classified under four genera—*Sivapithecus*, *Sugrivapithecus*, *Brahmapithecus* and *Ramapithecus*

Comparing the present day mammalian fauna of India with that of the Siwalik Period, of which the latest part comprises the early Pleistocene and is treated in detail in the next chapter, one feels as if one is living in a world from which all the largest, fiercest and strongest forms have recently disappeared The Siwalik carnivores, for instance, are more numerous than the living forms of similar size in the same area, while the ungulates exceed their living representatives in number in the proportion of about five to one there being something like hundred known Siwalik fossil species and only eighteen recent No less than fourteen extinct elephants and mastodons and two dinotheres are represented by a solitary living form Even such modern types as oxen and buffaloes have dwindled from eight to two As in other parts of the world, the Pleistocene in India is marked by the wholesale extinction of land mammals, a result no doubt of the revolutionary character of this Epoch, with its violent fluctuations of climate

CHAPTER SEVENTEEN

THE QUATERNARY PERIOD—I

The Pleistocene—The Ice Age

The Quaternary, the shortest of all the geological periods and unparalleled climatically in its development of the Ice Age, commenced about a million years ago It is sub-divided into the Pleistocene (the glacial age) and the Holocene or Recent (the post-glacial age) The Holocene began about 10,000 years ago Russian scientists, however, recognize three sub-divisions of the Quaternary, namely the Eopleistocene (Q_1), the Pleistocene (Q_2) and the Epipleistocene (Holocene, Q_3). Though moraines were first discovered in the Swiss Alps in about 1800, most Quaternary deposits have been known for a long time as products of flood, to which Buckland gave the name Diluvium in 1823 The Holocene was formerly known in Germany as Alluvium Venetz in 1829 first suggested that the glaciers formerly existed in northern Europe Evidences of extensive glaciation in northern North America were found some years later About a century ago, it was discovered that the Kashmir valley and its adjoining northern parts were also heavily glaciated in the past

The presence of ice in the past is inferred from the occurrence of boulder clay or glacial boulders which are often scratched and angular, the polished and striated pavements caused by the movements of glaciers over them, and the glacial moraines left behind after recession and melting of ice Other indicators are the U-shaped valleys carved out by glaciers, the widespread glacial debris over most of the glaciated area, the terraces formed along the banks of rivers by the fast moving waters released from the melting glaciers, and the fluctuations in sea level, if not due to tectonic movements Together with these physical evidences, the alternation of the cold loving and warmth-loving plant and animal populations in response to climatic changes provide ancillary proofs of past glaciation

During the Pleistocene, there were four major glaciations, popularly known as Gunz, Mindel, Riss and Würm, which in some countries are known by the regional nomenclature such as Nebraskan, Kansan, Illinoian and Wisconsin in the USA, and Weyborne, Elster, Saale and Weichsel in Germany and Holland Some experts, like Zeuner, use an entirely different set of names Regional names have been also

applied to the intervening interglacials such as the Cromer, the Clacton and the Hoxne in the British Isles, and the Aftonian, the Yarmouth and the Sangamon in North America In some countries, both the glacials and the interglacials are known by numbers as I, II, III and IV These correspond, under the classic Alpine system to Gunz, Mindel, Riss and Wurm which form a basis for comparison with the rest of the world The III or the Riss glaciation was perhaps the most extensive of all Recent research has brought to light that in addition to these four major glaciations, there were several periods of glacial advances and retreats and warm climate (Inter-stadials) during the glacials

Glaciation in the Himalayas

In the lesser Himalayas of Punjab, glaciers from the Dhaula Dhar Range spread out into piedmonts, the outflow from which reached the present level of 700 m in Beas valley during the first advance Two later advances, which did not descend to such a low level, could still transport vast blocks of granite Glaciated land forms are recognizable in some places in the foothills The Kangra valley is strewn with boulders and moraines below the Dhaula Dhar Range (Pl. 76 and 77) Behind the Dhaula Dhar, glaciers still persist, and glacial tarns in the upper part of the range prove the occurrence of a late phase of minor advance

The glaciers of the Karakoram and upper Indus drainage have been studied more thoroughly than those of the lower ranges on account of their influence on floods in the Punjab Garhwal and Kumaon, and the Everest–Kanchenjanga regions, are also well explored but most of Nepal and Bhutan are still imperfectly surveyed, and the north-east frontier has hardly been touched

Of all the four major glaciations in the Jammu & Kashmir State, the second was of maximum intensity with the glaciers descending down to the foothills There were two glacial advances during the second glaciation and four during the fourth The intervening interglacial periods were of much longer duration than the glacial periods In the adjoining region of the outer Himalayas, the Siwaliks, river terraces corresponding to glacial and interglacial stages have been recognized (Pl 78A and 78B) Various kinds of sedimentary rocks, belonging to the Pleistocene are clays, silts, sandstones and loess The clays may be varved and the silts generally laminated Large stretches of deep alluvial terraces comprising sands, gravels, and clays occur in the Sutlej valley in Hundesh beyond the central Himalayas

Conditions in Other Parts of the Indian Sub-Continent

Peninsular India was never under glaciation, but in several of its river valleys such as of Narmada, Godavari, Krishna, and Kortalayer in Madras gravel beds or conglomerates

GLACIAL BOULDERS (ERRATICS) AND MORAINES PARTIALLY BURIED IN CLAY, NEAR NAGROTA IN KANGRA VALLEY, 857 METRES ABOVE SEA LEVEL IN FRONT OF THE HIMALAYAN AXIS OF THE DHAULA DHAR RANGE

These boulders were deposited in the Pleistocene Epoch

A VIEW OF THE SITE NEAR PINJOR FROM WHICH SKELETON OF STEGODON GANESA WAS RECOVERED

are found intercalated with silts and clays Constituting the river terraces, these alluvial deposits are believed to show events in the peninsular region corresponding to those in the glacial regions Some of these have been correlated with the glacial and interglacial phases on the testimony of animal fossils

Many hundred metres thick sands, silts and clays with occasional gravel beds and lenses of peaty matter occur in the great alluvial tracts of the Ganges, the Brahmaputra and the Indus in the depression between the peninsular and extra-peninsular regions The deposits show a succession from the upper Eocene to the Holocene

During a glacial phase, the waters of oceans were locked up in the glaciers and consequently the sea level fell exposing more land During an interglacial the locked up water was released through the melting of ice as a consequence of which the sea level rose and transgressed the coastal areas The accompanying earth movements submerged or raised certain parts of coastal regions Raised beaches up to 30 m above the present sea level along the eastern coast in Orissa, Nellore, Madras Madurai and Tirunelveli and along the western coast in Kathiawar, and Mekran coast and estuarine deposits far inland in Gujarat and Rann of Kutch are some of the evidences of the emergence of land. Fossil woods and peaty deposits, a few hundred metres below the surface in Bengal Basin, Pondicherry and Bombay (Princes' Dock) provide the evidence for the submergence of land.

Glaciation in Other Parts of the World

Three great ice centres existed in Europe—one in Scandinavia, another in the British Isles and the third in the Alps The Scandinavian ice sheet extended into the heart of central and eastern Europe It was about 900 m thick at its centre which lay slightly to the east of the present mountain water shed The British ice sheet although confined to the British Isles except the south of England, sometimes formed an extensive and continuous ice sheet with the Scandinavian A network of valley glaciers characterized the ice centre in the Alps, where the higher peaks remained unglaciated The amount of glaciation decreased eastward because of the increasingly continental climate (Fig 69)

Several separate ice centres existed in America The Laurentian ice lay over the relatively low lying area of the eastern part of the Canadian Shield and it originated in the highlands of north-eastern North America Westward, the Laurentian ice was connected to the Cordilleran ice which extended over a distance of about 3520 km from the Columbia river to the Aleutian islands Innumerable glacier complexes existed in other places, the largest of which lay in the Sierra Nevada of eastern California With the exception of the Brooks Range, northern and central Alaska were never glaciated.

A SECTION OF THE KANGRA VALLEY NEAR PALAMPUR SHOWING BOULDER CLAY

The erratics are stuck in the upper layer of clay. The valley is made of clay deposits and moraines washed down from the Dhaula Dhar Range

A VIEW OF THE RIVER TERRACES (T2-T5) IN THE SIWALIKS, PINJOR, NEAR CHANDIGARH

A VIEW OF THE SITE NEAR PINJOR FROM WHICH SKELETON OF STEGODON GANESA WAS RECOVERED

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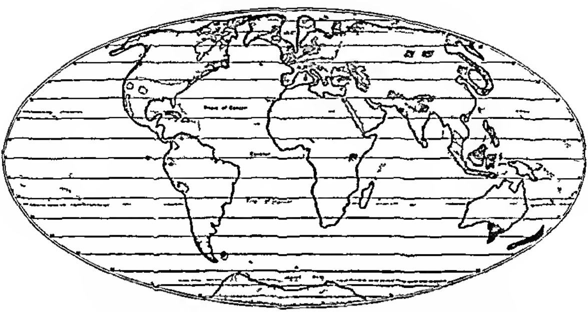

FIG 69 MAP OF THE WORLD IN THE MIDDLE PART OF THE QUATERNARY PERIOD The darker areas were glaciated (After Arldt)

A continuous ice sheet was developed in the South American Andes spreading over the low lands of Patagonia in the south.

In Asia, ice covering great parts of western Siberia and extending eastward across the Yenesei was the direct extension of Scandinavian ice sheet Other mountain ranges in Asia, Africa, Australia, Tasmania and New Zealand bore glaciers Even in the polar regions, the extent of glaciers varied considerably during the Pleistocene, the interglacials have also been recognized there

In the lower latitudes and arid regions, successive periods of abundant rainfall were followed by dry periods This is evidenced by the fluctuating lake levels and alternating lateritic and calcareous deposits of salt and mud

Crustal depression under ice load. The study of the shorelines has shown that under the immense weight of the ice, the crust of the earth in the northern hemisphere was deeply pressed down by at least 200 m The crust of the earth acts like a steel spring which is depressed under heavy load and tends to rise on removal of the load The Great Lakes and the Hudson Bay in North America and the Baltic Sea in Europe are the largest depressed regions of the Pleistocene glaciation These are still slowly rising as the ice has melted away Greenland is perhaps the most obvious example of a present day ice-depressed region Here, the ice cap is about 3360 m thick, while the central part of Greenland is at least 360 m below the sea level

Besides the accumulation of vast quantities of ice during the glacial age, most of the areas near glaciation had their soil, ground water and even bed rock frozen to varying depths up to 600 m, and a new word, permafrost, has been coined to denote these characteristic features Ground ice, once established, grows like common mineral crystals As melted ice water cannot penetrate the still frozen earth beneath, the soils on sloping permafrost get water-logged. For this reason, the northern Tundra is seen to be dotted with many lakes and bogs Buildings on permafrost are liable to subside if the frozen ground thaws out In the northern hemisphere, about 45 million sq km are now underlain by permafrost

Effects of glaciation on soil and ocean water. No effects of Pleistocene glaciation are more important than those concerning the soils of the northern hemisphere In Canada, many glaciers have scoured away the soil mantle as well as the upper weathered portion of the bedrock over wide areas The soil stripped away from north-eastern Canada was carried to the upper part of the Mississippi Basin, where the soils have been made deeper and richer Boulders and other rock debris carried away by the glaciers and deposited in the plains made cultivation difficult Previously, the boulders and the chaotic piles of rock debris in northern hemisphere, left by the melting glaciers, were thought to have been caused by Noah's flood Locally, however, the melted water had laid down finer sediments which are now found as patches of fertile soil The ice movements were mostly guided by lowlands, basins and troughs where new features have been introduced into the landscape after the disappearance of the glaciers The glacial deposits also, depending on their mode of deposition, have distinct topographic features

Other accompanying glacial effects include increased wind action and cooling of ocean waters It is believed that the Pleistocene glaciers behaved much the same way as does the Greenland glacier at present A large growing ice mass sets up anti-cyclonic action at its centre These air movements sweeping outward encounter the warm and moist air at the ice margin and cause maximum precipitation there Accordingly, the ice mass grows along its margin as seen today in Greenland glacier where wind blows outward for nine months in the year sweeping snow off to the margin and giving rise to a fringing glacier

PALAEOGEOGRAPHY

India

The present shaping of India took place during the Quaternary The Himalayan chain was uplifted to the present lofty heights and the uplift resulted in the formation of valleys

such as of Kashmir and Kathmandu Several lakes were also formed in the Himalayas such as the Karewa lake in Kashmir and Kathmandu lake in Nepal, which were later drained due to earth movements Chilka lake in Orissa also came into existence during the Pleistocene

Sea levels fluctuated along the coasts and the records of emergence and subsidence show that the coast line has been changing Coasts of Kathiawar, the Rann of Kutch and the eastern coast were elevated Raised beaches were formed in the districts of Tirunelveli and Ramanathapuram Amongst the recent evidences of submergence may be cited, Coringa near the mouth of Godavari, Kaveripatnam in the Cauvery delta, and Korkai on the coast of Tirunelveli, which were the flourishing sea ports about 1000 to 2000 years ago The rise of Allah band in Kutch is also a recent event The Madhupur jungle in East Pakistan was elevated recently by about 30 m and the course of the Brahmaputra was shifted westward

The rivers of the Indus system have shown a gradual shift to the west The present drainage pattern and the deltas took shape during the Pleistocene The Narmada formerly flowed more towards the south-west in Khandesh and joined the Tapti The straight courses of the Narmada and Tapti appear to be largely determined by faults due to compressional forces that acted from north to south producing E–W features during the final uplift of the Himalayas in Pleistocene times These basins are rift valleys formed by the sinking of land between roughly parallel faults "The straight wall-like escarpment of the Malwa plateau along the north side of the Narbada and of the Deccan plateau south of the Tapti-Purna valley in southern Khandesh" are intrinsically suggestive of this according to Sir Edwin Pascoe But as the rocks underlying the alluvium of the Narmada have been found to be usually members of the Vindhyan or Dharwarian formations it is certain that simple faulting may not be the sole cause of the formation of the northern edge of the Narmada valley, but differential erosion must also have played a considerable part It is known that during Cretaceous Period, a narrow gulf invaded deep into the Narmada and Tapti valleys The Narmada Basin may, therefore, be a remnant of some Gondwana basins along which the sea penetrated into Rewa in Madhya Pradesh to link with the extensive Productus Sea of the Persian Gulf region and Salt Range of West Pakistan

Almost all the rivers in the extra-peninsular India are of Pleistocene origin. The river Beas used to flow through Lahore and Montgomery districts and earlier joined the Chenab near Shujahbad from where the Chenab turned westwards About a thousand years ago, the Sutlej river instead of joining the Indus system, as at present, flowed into the Sarasvati (Hakra or Ghaggar) in Bikaner The Ghaggar is now lost in the desert and the channels of its various tributaries can now be traced The Yamuna was also a

large river in the past and it flowed south and south-west and shared its waters with the Sarasvati. Similarly, the Ganges, the Hooghly and the Brahmaputra have acquired their present courses during the Pleistocene and Holocene.

The final filling up of the fore-deep and the origin and progressive development of the Rajasthan desert are the other important features which came into existence during the Pleistocene and Holocene.

Other Parts of the World

The islands fringing the mainlands today were their parts during the Pleistocene, e.g. Ceylon of India; Andaman and Nicobar Islands of Burma; Malay Archipelago, Sumatra, Java, Borneo, etc. of the mainland of South East Asia; Britain of the European continent across the North Sea and English Channel; and Japan, Formosa and Kuriles of China. After the withdrawal of ice, the subsidence in the Baltic Basin created the Yoldia Sea. Evolution at a later stage converted this sea into a freshwater lake, the Ancylus Lake. A later sinking of the land followed by incursion of the sea created the Littorina Sea. The Alps and the Carpathians were finally uplifted to their present lofty heights.

Volcanoes bordering the Pacific Ocean and those of the Hawaiian Islands, Indonesia, Mediterranean and West Indies became active only during the Quaternary though they did exist during the Pliocene. Elevation and erosion characterized the Quaternary in Mexico, Alaska and western Canada. The coastal mountain ranges of the western United States, the Sierra Nevada region, the Cascade Range, the whole Colorado plateau region, etc. were finally uplifted during the Pleistocene.

The crustal deformation in late Tertiary culminating in the Pleistocene, has resulted in the formation of profound elongated depressions, sometimes thousands of metres deep, like those of the Great African Rift valley that zigzags from Palestine to Rhodesia, involving the Dead Sea, the Red Sea and the Tanganyika, Nyasa and the Albert lakes.

Climate. The variety and succession of climatic changes during the Quaternary, in extra-peninsular India, stand unique. Corresponding to the periods of glaciation and interglaciation, the climate was alternately cool and warm. The same trend is believed to be continued at present, which is considered a part of interglacial period after the last glaciation. It has been estimated that an average decrease of temperature during the last glaciation was 4°C and in temperate latitudes it was 8° to 12°C. The temperatures during interglacials were higher than today.

There is no physical evidence of recent glacial conditions in the peninsular India. But there are indications of colder climate than the present during a post-Tertiary Period. On several isolated hill ranges and plateaus, like the Nilgiris, the Shevaroys, etc. as well as on the mountains of Ceylon, are found temperate faunas and floras which are absent

in the low plains of the regions, but are related to the temperate faunas and floras of the Himalayas, the Shillong plateau of Assam, the Naga hills, and the mountains of Malaysia and Java Several Himalayan plants are found even on such isolated peaks as Parasnath in Bihar and Mount Abu in Rajasthan For example, the occurrence of the Himalayan plant, *Rhododendron arboreum*, and the mammal, *Martes flavigula*, on both Nilgiris and the mountains of Ceylon is significant More interesting is the occurrence of a species of wild goat, *Capra hylocrinus*, on the Nilgiri and Anamalai and on some hills further south. The only other known species of the genus *Capra* in India is *Capra* (*Hemitragus*) *jemhalicus* which lives in the temperate regions of the Himalayas from Kashmir to Bhutan The lizard, *Lygosoma sikkimense*, the beetle, *Thynsia wallichi*, the cicad, *Haphsa nicomache*, and a fly, *Sepsis cynipsea*, occur on the top of Parasnath and nowhere else in the plains except in close proximity to the base of the Himalayas There is little doubt that a great portion of the temperate fauna and flora of the south Indian hills has been living there prior to the glacial time "It would be possible" writes Pascoe, "for the species common to Ceylon, the Nilgiris and the Himalaya to have migrated at a time when the country was damper without the temperature being lower, but it is difficult to understand how the plains of India could have experienced a damper climate without either depression, a change in the prevailing winds, or a diminished temperature sufficient to check evaporation A depression would have caused a large portion of the country to be inundated by the sea, a change which in itself would have prevented rather than aided the migration of animals and plants A change in the prevailing winds would have been improbable so long as the distribution of land and water was in general what it is today. There are some grounds for accepting the remaining theory, therefore, that the temperature of the intervening plains was for an appreciable period sufficiently lower than it is now to permit some of the animals and plants from the Himalaya to wander south"

CHAPTER EIGHTEEN

THE QUATERNARY PERIOD — II

History of the Himalayas, Indo-Gangetic Plains and other Features of India

Some parts of the Himalayas have risen by at least 1500 m. since the middle Pleistocene The Himalayas are the highest mountains of the world, and their upheaval from the floor of the Tethys Sea is a great epoch-making event in the geological history of the Indian sub-continent They prevent the rain-bearing winds from the Indian Ocean passing out of the sub-continent and protect it from the cold and dry northern winds By reason of their altitude, they are cold enough for the formation of glaciers to feed their rivers Without these great mountains, the Indo-Gangetic plains would have been an arid and desolate country like the Thar desert of Rajasthan, which lies outside the path of the monsoon and is, therefore, almost rainless Nearly all the rain that falls in the Himalayas and all the snow that melts on them come to the sub-continent and only insignificant quantities enter Tibet

The Himalayan rivers have made the Indo-Gangetic plains, one of the most fertile regions of the world. But the rivers are subject to frequent changes in their courses A brief outline of the history of the Himalayas and their rivers is given below

THE HIMALAYAS

The Quaternary Period saw the final uplift of the Himalayas Time and again their present site was flooded by the Tethys Sea. Though the Himalayas rose out of this sea during the Eocene Epoch, some 50 million years ago, the sea basin was accumulating sediments that now form the rocks in the Himalayas, since the Cambrian Period half a billion years ago Further, the sediments of the Cambrian Period were deposited on a floor of pre-Cambrian rocks which had also passed through a long and complicated history These rocks form the bulk of the central Himalayan zone, comprising most of the lesser or middle Himalayas together with the Great Himalayas. The rocks are granites and ancient sediments that have been greatly altered by heat and pressure giving rise to gneisses schists, phyllites, etc These rocks are relics of what

was a mountain range which probably divided the Tethys into at least two geosynclines the northern of which developed under conditions permitting a fully fossiliferous succession to subsist from the Cambrian to the Cretaceous, while during the development of the southern, Cis-Tethys geosyncline, the environmental conditions were unfavourable for the existence of life for the same length of time The sea floor subsided concurrently with the deposition of sediments, so that there resulted a vast pile of thousands of metres of shallow and deep water strata

Certain major phases of the history of Himalayas are obvious From the Cambrian to the middle Carboniferous, their present site was dominantly an area of marine sedimentation for marine fossils are found at various levels of the mountains

The middle Carboniferous Period closed with a climax of mountain building activity Tethys withdrew from Chitral, Hazara, Kashmir, Spiti, Kumaon and other regions The new land that emerged was exposed to atmospheric erosion of varied duration Much of the northern borders of Gondwanaland was high and mountainous, so much so that the peaks were snow-clad and local glaciers descended into such seas as were left in the area paralleling the glacial flows in the high southern and northern latitudes of Tierra del Fuego and Alaska respectively Glacial boulder beds have been found in Sikkim in Garhwal-Kumaon mountains, Kashmir and in the Salt Range and Hazara in West Pakistan Later, in upper Carboniferous time when the climate became warmer, the all conquering Glossopteris flora took possession of the land and coal seams were formed locally When glaciers melted their water returned to the sea flooding the low-lying areas The sea level rose higher and the Tethys returned to the Himalayan region, and sedimentation again started The mass of sediments that was laid down in the Carboniferous sea is now found as rocks on Mount Everest Some volcanoes rose out of this sea In Kashmir, the Pir Panjal ranges, and in the eastern Himalaya, the Abor hills and the Subansiri in NEFA, were the sites of these volcanoes

With the return of the sea on the site of the Himalayas in the upper Carboniferous time, there began to be deposited marine sediments containing brachiopods, lamellibranchs, gastropods, crinoids, ammonites, etc pertaining to Permo-Carboniferous, Permian, Triassic, Jurassic, Cretaceous and Eocene times The sea floor subsided concurrently with deposition of sediments, so that there resulted a vast pile of thousands of metres of shallow and deep water strata representative of the above mentioned ages

Perhaps the most complete and best known sections of these strata, especially from the Triassic upward to the top of the Cretaceous, together with the Palaeozoic from the Cambrian to middle Carboniferous are exposed on the cliffs that constitute the magnificent escarpment of the Tibetan plateau in Spiti, Garhwal and Kumaon, and further east in Sikkim This zone is known as the Tibetan zone of the Himalayas in

contrast to the Cis-Tethyan zone of unfossiliferous rocks forming the middle ranges of the mountains

At the end of the Cretaceous, land conditions prevailed in the Himalayan region separating the Tethys on the north from a depression on the south which for some time took the form of a marine gulf extending from Jammu south-eastward as far as Lansdowne The evidence of land conditions are found in Ladakh and Hundesh, where there was estuarine sedimentation, with intermittent marine deposition during the upper Cretaceous Coal-bearing sandstones are also found capping the eroded surface of Cretaceous limestone and other older rocks in the Hazara district of West Pakistan Further, no marine Tertiary rocks have been found in the Karakoram region since the end of the Cretaceous Period The Cretaceous earth movements were associated with volcanism in north Kashmir and Hundesh which continued into the Eocene in conformity with the volcanic outbursts of the Deccan trap in the peninsula

The crustal movements that gave birth to the Alps have also been responsible for the formation of the Himalayas The movement that first outlined the belt along which the Himalayas were uplifted may have begun in the Cretaceous times, but such pre-Tertiary movement was probably mild, producing an incipient island arc, and there is little evidence to show that there was any real mountain building movement before the middle of the Tertiary Period. The gigantic masses of sediments that had been accumulating upon the gradually sinking floor of the Tethys, since the upper Carboniferous, disturbed the gravitative equilibrium of the crust towards the end of the Eocene, when a series of intense mountain building movements, separated by periods of some quiescence, started, resulting in the uplift of the Himalayas

The process was begun by the outpouring of the Deccan trap lava through numerous fissures during the late Cretaceous and early Eocene The abnormal tension of the earth's crust caused by the extraordinary sinking of the Tethys thoroughly upset the internal equilibrium of the earth The equilibrium was adjusted only by the most violent changes starting with great outbursts of volcanism at many centres and ending in gigantic convulsions that forced up the deposits of the Tethys into a great mountain system It is estimated that about 1,666,000 cu km of lava, which exceeds in bulk the entire Himalayas, was poured out from the bowels of the earth

The continued sinking of the Tethys is presumed to have been caused by crustal weakness During sinking of the sea there was lateral thrust which narrowed the basin The narrowing of the basin upheaved the sediments, and surplus sedimentary materials were forced up into folds above the basin to form the Himalayan chain The margin of the upheaved mass also yielded under strain, developing fractures in many places As the sinking sea floor reached deep into the region of higher temperature and pressure,

the lower layers of sediments were melted into "magma" which invaded the crumpled and crushed overlying sediments as intrusions or as lava flows These now form the central axis of the Himalayas Some of the rocks have been squeezed up and out by the lateral forces from two sides and thrust into overturned folds and faults Many of the overturned limbs are displaced as flat-lying folds known as nappes

The upheaval of the Himalayas has taken place in three major phases The earliest phase was at the close of the Eocene, when the Eocene nummulitic limestone and the underlying older strata that had been accumulating on the floor of the Tethys since the upper Carboniferous were uplifted into ranges of considerable altitude (4500–6000 m), found in Kashmir, Hundesh and in parts of eastern Tibet With this uplift, all traces of the Tethys in the Himalayan region vanished The next upheaval took place towards the close of the Miocene when the sediments deposited by rivers in estuaries along the flanks of the infant Himalayas were upraised These now constitute the middle or lesser Himalayas The last upheaval commenced after the Tertiary and continued into the sub-Recent through the Pleistocene The movements involved the uppermost Siwalik freshwater sediments

It is now generally believed that the uplift of the Himalayan system of mountain ranges is due to movements of two solid continental masses on two sides of the Tethys, directed towards one another The Central Asian continental mass, Angaraland, slowly moved from the north to the south under pressure from the floor of the Arctic Ocean, and the northern edge of the Indian continental mass, Gondwanaland, became downwarped by the northward compressive force from the Indian Ocean The Himalayan portion of the Tethys gradually shifted southward and became narrower, assuming its present trend, in early Eocene time The presence of tongue-like projections of Gondwanaland, one in the Kashmir-Hazara region—the Punjab wedge, and the other in the north-eastern extremity of Assam—the Assam wedge, have moulded the pattern of the Himalayan chain The effects of these two wedges can be clearly seen in any relief map of India It will be seen that the Himalayan chain occurs as a huge arc between Nanga Parbat in the west and Namcha Barwa in the east The convexity of the arc points south towards the Indian peninsula Though geographically the Himalayas are considered to be limited between these two points, the Nanga Parbat and the Namcha Barwa, the rock formations seem to be suddenly folded round at these points and to turn southward in rather parallel ranges

Structure of the Himalayas The Himalayas can be divided structurally into four well-marked longitudinal zones The southernmost zone bordering the Indo-Gangetic plains is a belt of foothills, the Siwalik hills, 8–48 km wide and about 915 m. high.

The Siwalik hills are mainly river deposits of middle Miocene to lower Pleistocene age, folded into arches (anticlines) and troughs (synclines) Many of the anticlines have been broken by faults—dislocations due to slipping of the rocks along a plane of fracture (fault plane) The fault planes steeply sloping into the hills have given rise to steep scarps facing the plains

Immediately adjacent to and on the north of the Siwalik hills, lies the sub-Himalayan zone or lesser Himalayas, 65 to 80 km wide and of an average altitude of about 3000 m The rocks here are mostly unfossiliferous

Two great thrusts have been traced in the Kashmir Himalayas The southern of these is known as the Murree thrust by which rocks ranging in age from Carboniferous to Eocene have been pushed forward to ride over the mid-Tertiary rocks The northern thrust known as the Panjal thrust is more significant It has driven the pre-Cambrian schists and slates of the central Himalayas to overlie the Carboniferous–Eocene rocks (Fig 70) In the Simla Himalayas, at least two nappes of pre-Cambrian and Palaeozoic rocks are found to overlie the Tertiary rocks of the outer Himalayas Small remnants of once extensive thrust mass (nappe) of metamorphosed older rocks that have survived erosion form the upper part of the ridge on which Simla is situated.

Further north is the central Himalayan zone (Great Himalayas) of high ranges with snow clad peaks It consists mainly of metamorphosed sedimentary rocks intruded by

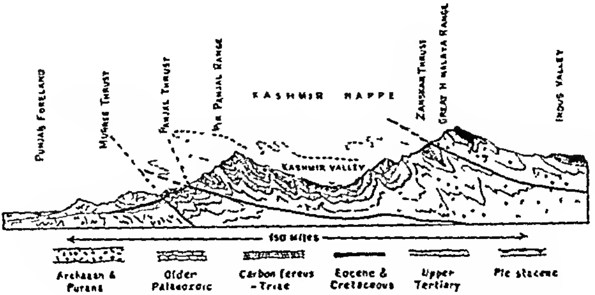

FIG. 70. A DIAGRAMMATIC SECTION ACROSS THE KASHMIR HIMALAYAS SHOWING STRUCTURAL FEATURES. The valley is composed of Pleistocene alluvium of lacustrine origin (After Wadia)

the lower layers of sediments were melted into "magma" which invaded the crumpled and crushed overlying sediments as intrusions or as lava flows These now form the central axis of the Himalayas Some of the rocks have been squeezed up and out by the lateral forces from two sides and thrust into overturned folds and faults Many of the overturned limbs are displaced as flat-lying folds known as nappes

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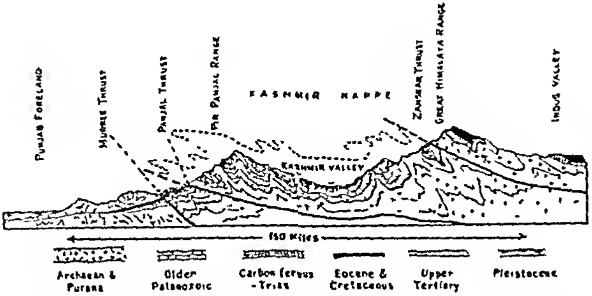


Fig 70. A diagrammatic section across the Kashmir Himalayas showing structural features. The valley is composed of Pleistocene alluvium of lacustrine origin (After Wadia)

granites, etc The folds here are more densely packed, giving rise to overfolds, reversed folds and intensive thrusting

The northernmost zone is the trans-Himalayan, where full sequence of the fossiliferous Himalayan rocks from the Cambrian to the Eocene are found Except in Kashmir in India and Hazara in West Pakistan, this zone lies in Tibet and is, therefore, referred to as Tibetan zone

All these thrust faultings took place during the main Himalayan upheaval in Miocene times In later Tertiary and Pleistocene times, further thrust movements of much less intensity took place affecting the outer Himalayas, when early and middle Tertiary rocks were pushed over the later Tertiary and Pleistocene rocks

The young Himalayas and old rivers. Though the Himalayan mountain chain is young, many of its rivers, the Indus, the Sutlej, the Bhagirathi, the Alakananda with other tributaries of the Ganges system, and the Brahmaputra, are older than it These rivers during the process of mountain formation by the folding and uplift of the bed-rocks, kept very much to their old channels so that the erosion of the valley kept pace with the elevation of the mountain The rivers have, therefore, developed deep transverse gorges that are a characteristic feature of the Himalayas

"It is believed", writes Sir Cyril Fox, ' that the ancient Tsanpo or upper Brahmaputra was diverted into India through the Assam Himalaya by an active young river, which flowed into the Bay of Bengal, cutting back its head waters and so capturing the drainage of the Tsanpo" Heron believes that in some distant future the river Arun may capture the upper waters of the Tsanpo and so deprive the Brahmaputra of some of its drainage There are other examples of such river capture in the Himalayan region

It is thought that the Himalayas have not yet attained their maximum elevation They are still rising The frequent changes of river courses are mainly due to the uplift of their watersheds The frequency of earthquakes in the Himalayas and in the plains in their neighbourhood indicates that the mountains are still under tension and have not yet settled down to their equilibrium plane

Himalayan Rivers

Reference has been made earlier to the great late Tertiary river, known as the Siwalik or Indobrahm. It occupied the pronounced sag or trough, which was produced in the frontal part of the Himalayas by the compression which folded and uplifted the Himalayan sediments in Eocene and subsequent times This extinct river emanating from Assam flowed in a north-westerly direction upto the Potwar in West Pakistan, where it joined the present Indus which flowed south-west into the Sind gulf, which extended much further inland It is supposed that two separate rivers or two branches of the same

river cutting back from the Bay of Bengal, across the region between what are now the Rajmahal hills in Bihar and the Garo hills in Assam, deflected the westerly flowing Indobrahm southwards and produced the modern Ganges and the Brahmaputra rivers

There seems to be sufficient evidence to show that the Siwalik river had flowed along the foot of the Punjab Himalayas where "it was reduced by the piecemeal capture of the portion lying between the Jumna and the Jhelum by its own tributaries the Jhelum, the Chenab, the Ravi, the Beas, the Sutlej and the Ghaggar Each of these tributaries now occupies a wide valley well below the level of the plain The capture took place in post-Siwalik times and is probably quite recent" It is believed that the capture was due to depressions in the valley floor caused by earth movements from the north-west Along these depressions, the tributaries named above cut their way back and captured various parts of the parent river, and eventually the Ghaggar became the final channel of the parent river Today the puny Soan of the Potwar plateau (Rawalpindi) in West Pakistan is the only relic of the old Siwalik river

There cannot be any doubt that the present Yamuna river, from near Karnal, north of Delhi and the present Ghaggar, from near Nahan east of Ambala, flowed westward They joined near Suratgarh in Bikaner and continued to flow as the Hakra through Bahawalpur to join the Indus The dry bed of the Hakra or lower Ghaggar is still recognizable The Sutlej seems to have flowed along the Ghaggar channel more than once in historic times Sir Aurel Stein recorded pre-historic settlements near Fort Abbas where an old dry river bed indicates the channel by which the Sutlej entered the Hakra The Sutlej flowed through the present dry and abandoned course of the Hakra, independent of the Indus and found outlets into the Rann of Kutch The Beas had also an independent course between its present course and that of the Ravi meeting the Chenab between Multan and Uch

The Sarasvati originated in the Siwalik hills of the Ambala district, where the alluvial fans of the Yamuna and the Sutlej meet There are old tributaries of the Sarasvati which come from near the place where the Sutlej emerges into the plains It is, therefore, probable that it derived its waters largely from the Sutlej and also from the Yamuna through the Chutang and became "the chief and purest of the rivers flowing from the mountains to the sea", according to Vedic tradition

After the Ganges captured the head-waters of the eastern branch of the lower Yamuna and the old Beas captured the Sutlej the Sarasvati was reduced to a small stream losing itself in the desert of Bahawalpur and Sind, where the greater part of its channel became the dry Ghaggar or Hakra This happening within historical times is responsible for the Hindu legend that it is the Sarasvati which joins the Ganges at Prayag near Allahabad

The name, Sarasvati, is still given to the upper part of the Ghaggar, rising in Sirmur in the Garhwal Himalayas

An organic connection between the Indus and the Ganges is inferred by the presence of the same species of dolphin, *Platanista gangetica*, in both the rivers This cetacean is found only in the Ganges, the Brahmaputra and the Indus It never enters the sea The Chelonia living in the Indus and Ganges are identical, while those of the Mahanadi, etc belong to different subspecies or local races

INDO-GANGETIC PLAINS

The Indo-Gangetic plains which lie at the foot of the Himalayas from Hazara to Assam, mark the side of a deep basin of estimated depth of 1050 to 6000 m which resulted from the compression exerted on the peninsular margin against the advancing crustal waves from the north The basin has been filled up with river alluvium derived from the rising Himalayas as well as from the plateau on the south

Alberuni (Abu Raihan Muhammed bin Ahmed), a scholar with keen perception came to northern India in early 11th century, and made a remarkable observation on the structure and formation of the Indo-Gangetic alluvium 'If you have seen the soil of India with your own eyes and meditate on its nature", wrote Alberuni—"If you consider the rounded stones found in the earth, however deeply you dig, stones that are huge near the mountains and where the rivers have a violent current, stones that are of smaller size at greater distance from the mountains, and where the streams flow more slowly, stones that appear pulverized in the shape of sand where the streams begin to stagnate near their mouths and near the sea, if you consider all this, you could scarcely help thinking that India has once been a sea which by degrees has been filled up by the alluvium of the streams".

As the spurs of the Himalayan ranges rise from the plains as land rises from the sea and also because of the occurrence of Subathu beds (Oligocene ?) about 64 km E S E of Hardwar, many people think that the Gangetic plain is an ancient sea-bed filled up by alluvial deposits As early as 1894, W T Blanford of the Geological Survey of India doubted the correctness of this supposition as no marine Tertiary bed has been found on the margins of the plains east of Delhi Recent drillings for oil by the Oil and Natural Gas Commission in Uttar Pradesh and Bihar have not encountered any marine rocks younger than the Mesozoic The only marine features of the Gangetic alluvium are a few brine springs and a deposit of gypsum in the form of selenite found in the Hamirpur district of Uttar Pradesh 'The former are", according to Pascoe, "not numerous and cannot be accepted as proof of marine deposition as far as the alluvium itself is concerned." The selenite crystals are entirely confined to the older *Kankar-*

bearing alluvium and are thought to indicate the sites of submerged springs Sparsely scattered pieces of selenite occurring in the carbonaceous materials below the surface of old alluvium in Dholpur of Rajasthan are associated with freshwater molluscs

The large rounded stones mentioned by Alberuni as occurring near the mountains where the rivers have a violent current refer to the disintegrated products of conglomerates and sandstones which form the Siwalik hills These are brought down by streams from the steep outskirts of the Himalayas and deposited along the northern margin of the plains The deposits have formed a broad forest-bearing zone known as the *Bhabar* in Uttar Pradesh

It, therefore, seems certain that the sea never reached the upper tract of the Indo-Gangetic plains later than Oligocene, but it covered portions of lower Sind on the one side and Bengal on the other as proved by recent drillings for oil From recent changes in the delta of the Ganges and from historical data, it is believed that practically the entire Ganges valley, east of Delhi, was swampy and mostly unsuitable for habitation, 5000 years ago

Differential movement in Indo-Gangetic alluvium The great depth of the Ganges alluvium, as recorded by borings, indicates subsidence of the Gangetic plain simultaneously with deposition Except near the delta, the greater part of the Gangetic plain is above the level of the highest flood of the Ganges and its tributaries, indicating either the area has been uplifted or the delta region has subsided within relatively recent times In East Pakistan, the raised tract, known as the Madhupur jungle, north of Dacca in the midst of the deltaic region, and low marshy plains of Sylhet and Mymensingh, which during the rains become almost a freshwater lake, indicate differential movements Ancient alluvial areas enclosed within rock basins along the courses of the Narmada, Tapti, and Purnea rivers are also uplifted, and it is evident that a certain amount of irregular warping has affected India in Pleistocene times As a result, the old alluvium and the one still in process of formation can be readily made out They are commonly known in north India as "*bhangar*" and "*khadar*" respectively The older alluvium is but a continuation of the Siwalik sequence and has yielded fossil teeth and bones of living animals, such as the ox, horse, camel and dog as well as Palaeolithic flints and tools at certain sites In some places, such as the Kharian hills, south-east of the Jhelum, upper Siwalik deposits are succeeded in a natural order of superposition by older and newer alluvium Usually the *khadar* is confined to the neighbourhood of river channels except in the deltaic plains, and the *bhangar* to relatively higher grounds The dominant silt throughout the Indo-Gangetic alluvium is a sort of sandy clay. A kind of concretionary carbonate of lime, usually in the form of nodules, called *kankar*,

occurs particularly in the older alluvium. Sometimes massive forms of calcareous beds are also found and at times the calcareous materials fill cracks in the alluvial deposits or in older rocks. The *kankar* nodules, the calcareous beds, etc. are formed either from the decomposition of the debris of older rocks or from fragments of limy materials contained in the alluvium.

The older alluvium is mostly made up of massive clay, pale reddish brown in colour, which on exposure, very often, turns yellow. In Bengal and Bihar, pisolitic concretions of hydrated ferric oxide, from the size of a mustard seed to that of a pea, are disseminated throughout the clay.

The newer alluvium is composed of coarse gravels near the hills, especially along the base of the Himalayas, sandy clay and sand near river channels, and fine silt consolidating into clay in the flat river plains and the deltas. Beds of impure peat are common in the

FIG 71 MAP OF INDIA SHOWING THE DISTRIBUTION OF ALLUVIUM IN THE PLEISTOCENE AND RECENT EPOCHS. These alluvial deposits are the principal reservoirs of ground water in India

delta of the Ganges; freshwater shells are more common in the newer than in the older alluvium, the species being identical with those now living in the rivers and marshes

The greater part of the Assam valley consists of *khādar*, liable to flooding.

In West Pakistan, the Potwar Basin is regarded by D. N. Wadia as the north-westerly ramification of the Gangetic trough, the succession of rocks in the folded basin encompassing 7500 m. of sediments in one conformable sequence, and epitomizes the Tertiary geology of northern India and West Pakistan.

The Indo-Gangetic alluvium has provided India with her most fertile soil which supports a large part of her population. It is also a vast reservoir of ground water, and wells and tube-wells can be sunk with ease. The extent of the alluvial belt is shown in Fig. 71.

OTHER FEATURES OF INDIA

The Thar and Indus Deserts

The tract situated between the Indus and the Aravalli hills is known as the Thar or Great Indian Desert, a land of sand-hills of the north African *seif* type. The sand-hills occur as long narrow ridges in the prevailing north-westerly direction of wind and may be as much as 60 m. in height and 3 km in length. The *barchan*, or transverse, crescentic type prevails to the north and east, and there are extensive areas of gently undulating land of "whale-backs of sand" and waves of sand which appear to be fixed and bear a thin covering of tall *muny* grass and small shrubs. The enclosed area of Jaisalmer, Barmer and Pokaran is rocky and has fewer sand-hills. The greatest accumulation of blown sand is seen on a strip in the north of the Rann of Kutch. The sand derived from the disintegration of local rocks and also from the Rann of Kutch is driven by the south-westerly gales which blow across the desert for several months of the year. Unimpeded in its advance by the streams, the sand has encroached upon the land until no district is entirely free from it, excepting those lying immediately at the foot of the Aravalli range, where several water courses are able to sweep back the sand blown into them.

From the investigations carried out by La Touche, which have provided the above data, it is found that the local rocks have furnished 90 per cent or more of the sand of western Rajasthan. The accumulation of sand is due mainly to the low rainfall and to the consequent absence of streams, aided by the salt-laden winds and saline surface conditions which prevent the growth of much vegetation.

The part of the country lying west of the Aravalli up to Cambay and Karachi receives very little rain as there are no mountains in this region. The monsoon climate probably became established during the Miocene when the Himalayas rose high enough to obstruct

the southerly winds causing precipitation of moisture on its southern flanks It is known that the Cambay-Ahmedabad-Thar region was occupied by the sea during the Tertiary and Pleistocene times This sea in the Pleistocene times might have extended to some distance north of the Rann of Kutch into the valleys of the Indus, Sarasvati, Hakra and Luni Further, the lowering of temperature during glaciation and the presence of the great basin of the Siwalik river also contributed to the humid climatic conditions of Rajasthan until sub-Recent times But, with the disappearance of the Siwalik river and withdrawal of the sea from the Thar-Ahmedabad region, desert conditions must have set in well after the advent of man

The sand-hill phenomenon of the Thar desert is repeated on a smaller scale in the Sind-Sagar Doab (Do-ab meaning two rivers) between the Indus and the Jhelum and in the Bari Doab between the Ravi and the Sutlej, but is absent in the Rachna Doab between the Chenab and the Ravi Crescent-shaped sand dunes are seen in the sandy desert of western Baluchistan where the dunes are slowly advancing over the plains The low hill ranges between Amir Chah and Saindak are now buried under sand

Salts in Lakes and in Sub-surface Indo-Gangetic Water

The sub-surface water in many places of the Indo-Gangetic alluvium and practically the whole of the desert region from the coast of Kutch and Sind northward and north-eastward to the borders of Delhi and Bahawalpur is charged with salts In dry weather, the salts appear as efflorescences at the surface and render the soil unfit for cultivation and the water in shallow wells unpalatable Such efflorescences, known as *reh* or *kallar* consist generally of sulphates, carbonates and chlorides of alkalies The alkali impregnated land, unsuitable for cultivation, is called *usar* land. In Rajasthan, on the borders of the Bikaner desert, shallow basins of internal drainage such as at Sambhar and Didwana are filled by the annual monsoon rain and dry up to yield the common domestic chloride salt In some places, as at Pachpadra, subsoil brine is raised for salt making To this category belong the numerous salt-pools known as *dhands* in Sind and Khairpur in West Pakistan, which are used for their carbonate contents

Various explanations have been offered regarding the origin of the subsoil salinity and of the salt lakes and pools of Rajasthan and Sind. The water in the rocks of western Rajasthan is generally so much mineralized that its suitability for irrigation and other useful purposes is limited Some of the lakes are probably remnants of lagoons left behind by the receding Arabian Sea of the late Tertiary Period. But in the absence of calcium and magnesium salts in most of the Rajasthan salt lakes, it is difficult to attribute sea water as their source Moreover, lakes like the Sambhar, Didwana, etc lie within the impervious area of the Aravalli schists and at comparatively higher levels to be affected by

the salt that may be brought by underground percolation from the Salt Range of West Pakistan into parts of Rajasthan In this area of Rajasthan, there are also no evidences of salt deposits or any signs of marine sediments It has been suggested by Sir Thomas Holland and W A K Christie that the supply of salt to the Sambhar lake is derived from monsoon winds blowing from the Rann of Kutch and carrying the salt either as particles of dust or sprays of sea water deposited over the desert sands from which it is washed out by rain and transported to the lakes where it is deposited by evaporation of the water To the question, whether such large quantities of salt, more than 150 000 tonnes, could be annually transported by the wind from the Rann of Kutch to Sambhar, S L Hora has remarked that "if the weather was cyclonic at times, there would be no difficulty, for he knew that rains of fishes are caused by cyclones"

Another salt lake, yielding sodium salts, is the Lonar in Maharashtra It forms a deep crater-like depression, and is thought to be of "explosion crater' origin, situated as it is within the Deccan trap area, others consider it to be due to subsidence, probably caused by the impact of a giant meteorite which has since been eroded away

Lakes which have an outlet, contain fresh water, unless they have direct connections with the sea, so that sea water can enter them The Chilka lake in Orissa is an example of this kind There are only a few natural freshwater lakes in India and these are found in the Himalayan region, and have been formed in various ways, such as the damming of a valley by a glacier which has descended down another valley Such lakes are usually small and are commonly associated with the present day Himalayan glaciers as the Chombu glacier in Sikkim

The filling with water of depressions previously carved out by glaciers has given rise to the series of lakes in the long and narrow valley of Pangong in Kashmir

The Kumaon lakes, except Khurpa Tal and other small lakes near Naini Tal, have been formed by landslips across the valleys. The origin of Naini Tal and Bhim Tal is not clear Since Naini Tal has its outlet over solid limestone, it may have been produced by the collapse of the surface caused by the removal of limestone by the solvent action of underground water Many of the little lakes in the limestone tracts of the Khasi and Jaintia hills of Assam and on the Shan Plateau of Burma, have a similar origin This phenomenon also occurs where the underlying rock is of rock salt, as at Pidh near Dandot in the Salt Range of West Pakistan The Wular lake, the Dal, the Anchar lake the Manasbal lake and several large swamps in the Kashmir valley are produced by landslips or moraine materials damming valleys

The sacred lake of Manasarowar and the adjoining Rakas Tal lie respectively 4530 m and 4515 m above sea level, north of the Nepal Himalayas. According to Hindu mythology these lakes are the traditional sources of the Indus, Brahmaputra

Ganges and the Sutlej and are in fact connected with channels that arise in their immediate neighbourhood It is not improbable that these lakes are portions of glacial valleys across which moraines form natural embankments

The Karewas of Kashmir

Among the deposits of the Ice Age are the Karewas which occupy nearly half of the Kashmir valley, and lie at an altitude of about 1700–3300 m The Karewas are partly lacustrine and partly fluviatile in origin, deposited in an elliptical synclinal basin between the Great Himalayas on the north-east and the Pir Panjal on the south-west. The deposits consist partly of low-lying alluvial materials, not much raised above the level of the Jhelum river which drains the Kashmir valley, but mainly of older deposits which form the elevated plateaus or terraces on the left bank of the Jhelum The separation of the older part from the recent alluvium has taken place by uplift and tilting, probably contemporary with the final folding and thrusting of the adjoining ranges. The total thickness of the Karewas is about 1430 m divided into lower and upper Karewas, separated by coarse deposits of second glaciation The lower Karewas are composed of dark and grey shales and contain two horizons of lignite They are referred to early to mid-Pleistocene The upper Karewas are made up of alternating beds of thinly laminated yellow marls, silts and sands Palaeoliths have been found associated with these deposits

Nepal Valley

The valley of Nepal is comparable with the alluvial basin of Kashmir in being a longitudinal valley lying along the general strike of the strata It is a group of confluent valleys with high dividing spurs An extensive upland region, called Tanr, corresponds to the Karewas of Kashmir and to the *bhangar* of the Gangetic plain Beds of peat occur at various levels in the valley and are used for brick and lime burning A clay, coloured blue by the free dissemination of blue specks of mineral vivianite, phosphate of iron, is widely employed for top-dressing the fields

Oscillating Shorelines of India

Since the late Tertiary, the coasts of India have oscillated between shallow marine and low-lying marshy or estuarine conditions

As a general rule, creeks, inlets and promontories are rather rare and those of any magnitude to be seen in the east and west coasts are the results of minor emergence and subsidence during the Quaternary Period.

The Chilka lake in Orissa, the Pulicat in Andhra Pradesh, the lagoons of Kerala and

western Mysore, owe their origin to sand spits or bars, and in the course of time they will be filled up in the same manner as is happening today to the lagoons near Mercanum to the north of Pondicherry, or to the Kolleru lake, formed by the union of the deltas of the Krishna and Godavari rivers. The greater part of the east coast has been formed in this way and later elevated. The deltas of the Cauvery and Penner rivers are complete, as no new land is being formed in the sea opposite their mouths, whereas those of the Ganges and Brahmaputra are extending outwards, so that land is being continually added to the shore where these two great rivers enter the Bay of Bengal.

At the southern end of the Peninsula, a calcareous gritty marine sandstone of sub-Recent age fringes the coast from Cape Comorin to the Pamban channel. This sandstone forms the islets in the Gulf of Mannar on which coral reefs are now growing. The island of Rameswaram is built up of a coarse and current-bedded calcareous sandstone containing broken shells and corals of the Recent age. Its northern shore displays an upraised coral reef, about 1–3 m. in thickness and the southern shore is undergoing a steady submergence. Judging from the thickness of coarse sandstones exposed at Tiruchchendur and other places, it appears that the eastern part of the southern tip of the Peninsula has been raised at least 9–12 m. during post-Pleistocene time. Near Dhanushkodi, the beach has advanced nearly a mile north-westward, with the result a number of buildings have gone under the sea during the last 50 years. Amongst the evidences of recent subsidence, mention may be made of the submerged forest in the Valinukam Bay, Tirunelveli district, while the occurrence of peat about 5 m. below ground near Point Calimere, on the Tanjore coast may be due to the same general cause.

In the coastal regions of south-west Madras, Kerala and Mysore, the Pleistocene movements have brought the Warkalli (Miocene) rocks and similar formations to the surface, but they are also responsible for the subsidence near Cape Comorin and other places. Further proofs of movements in comparatively recent times along the coast are to be found not only in the terraced character of the coast itself, but also in the presence of buried upright trunks of trees in Kerala at Chattanur and Thottapalli, where they are recovered for use as fuel. Chacko has recorded recent coral reefs under the alluvium near Changancheri in Kerala.

A general emergence seems to have extended to the south of Goa through Malabar, though there may have been local complications, for example, at Malpe near Udipi and at Bhatkal further north where emergence followed submergence as indeed was the case in Goa itself. The uplift of the south-west coast probably took place not much before the beginning of the Christian Era.

The Konkan coast with its cliffs and inlets is a recent faulted scarp and its shore lines are due to marine denudation with local variations of subsidence and uplift; thus on

Bombay Island, a littoral concrete platform occurs on the west and there are submerged forests on the east Further south, on the Kerala coast, only active marine erosion is visible along the cliffs at Varkala, and Tellicherry in Malabar

Further to the north again, around the Gulf of Cambay, the presence of littoral concrete on clay-bearing mangrove roots *in situ* seems to indicate both emergence and subsidence.

During the Pleistocene, the Cambay-Ahmedabad-Thar region was under the sea, indeed, a salt lake termed 'Nal' in the heart of the alluvium-covered plain of north-west Gujarat, is a remnant of this former sea with its marine deposits

The changes in the relative levels of land and sea along India's coast line, briefly outlined here, proceeded so slowly as to be hardly perceptible during the average span of human life but there have been occasions in the past, and doubtless will be in the future, when this normal rhythm of events is suddenly interrupted by violent earthquakes On June 18, 1819, for example, an earthquake caused a depression more than of 320 sq km, on the western border of Rann of Kutch, which was quickly invaded by the sea At the same time there was an uplift of a barrier, 80 km or so in length, the difference of level between the depth of the depression and the height of this barrier being about 6 m

The Rann of Kutch

The Rann of Kutch is an ancient inlet of the sea which for the most part has dried up due to silting up aided by slight tilting of the land It is an extensive marshy salt plain scarcely rising above the sea level Its surface, covered with such a saline efflorescence, never cracks even in the hottest weather During the monsoon, the Rann is liable to flooding not only by the rain but also by flood water from the streams, the Luni and the Sarasvati The parts of the tract that were depressed by the earthquake of 1819 are still under water There can be little doubt that the Rann was a gulf of the sea within recent times It had sea ports on its shores, for anchors and remains of sea going ships are reported to have been found embedded in the mud Borings in the Little Rann indicate estuarine conditions succeeded by marine in recent times In the neighbourhood of the Nal, a large shallow lake of brackish water, cerithid shells have been found indicating estuarine conditions that prevailed until recently and confirming that the Rann of Kutch is an old marine inlet silted up in recent times

Teris

Dunes of wind-drifted sand occur in some parts of the coastal plains of Orissa, in Ramanathapuram and Tirunelveli in Madras, near Surat, Broach, and

parts of Kathiawar and the Kutch coasts in Gujarat. At a few localities in South India, pre-historic artifacts have been found in the dunes. Logan recorded quartz flakes of Neolithic age in a *teri* (red sand dune), a few miles north of the Tambraparni river in Tirunelveli. Recently, Neolithic artifacts consisting of microliths fashioned out of chert and two or three polished cleavers made out of quartz and granitic materials have been found embedded in a red sand dune to the north of Oriyur in Ramanathapuram district. This particular dune is of a Recent age. *Teris* also occur on the south-west coast of India from south of Trivandrum to Cape Comorin. Angular fragments of charnockites and garnetiferous gneisses as well as numerous small chips of quartz, suggestive of Neolithic artifacts, have been found in them.

Mud Banks

A peculiar feature of the shallow sea immediately off the south-west coast of South India is the occurrence of smooth water tracts known as mud banks. This is of Recent or sub-Recent origin, best seen near Alleppey, Cochin and Calicut. These mud banks have the unusual property of providing remarkable quietness to the waters above them, even during the roughest monsoon weather, so that ships can safely ride on them and at times can take in water alongside. The mud itself is dark green in colour, very fine-grained, with an oily feel. It also contains quantities of recent foraminifers, as well as diatoms. Although much has been written on the mud banks, no conclusive explanation of their behaviour has yet been forthcoming.

According to Coggin Brown, the mud is derived from the clayey materials of laterite, resulting from the alteration of gneisses and brought down by the present and past rivers. The presence of artesian fresh water in a bore hole at Cochin being indicative of natural outlets of water-bearing sands in the sea bed, Coggin Brown suggested that the seasonal increases in the hydrostatic head of such water sands, or unusually severe erosion of their outcrops by wave action at sea, might have a direct bearing on the formation, growth and movement of mud banks. This will also account for the huge bubbles or 'cones' of water and mud seen in the Alleppey mud banks.

On balance, they move southward due to the suspension of the soft mud by wave action or ground swell, and the carrying or rolling of the material by the prevalent currents, which are from north to south, thus leading to the eventual deposition of the material on the lee side of the banks.

Laterite

Laterite, a peculiar reddish or mottled, vesicular clayey ferruginous rock, pisolitic or massive, is formed as a supesficial alternation of rocks in regions subjected to alternat-

ing wet and dry seasons The effect of lateritic weathering is to remove the silica of rocks, leaving a concretionary mixture of hydrated oxides of iron and aluminium, with smaller percentages of other oxides When the laterite is almost free from silica and contains abundance of the hydrates, either of iron, aluminium or manganese, it constitutes valuable ores of these metals

Laterite is of wide distribution in India, from Assam to Cape Comorin, and it occurs dominantly as cappings on plateau highlands, but is not confined to such reliefs alone and caps the eastern and western coastal plains as well It is largely of Pleistocene age, but it may also be forming now, while some was formed in Eocene or even earlier

Pleistocene and Recent Volcanism

There are two regions of Pleistocene and Recent volcanic activity situated along the mountain arcs which meet the Himalayan range at its eastern and western extremities The eastern region is situated on the Malayan arc with the best known extinct volcanoes, Pupa in Burma and "Smoking" Barren Island in the Indian Ocean In 1795, Barren Island was throwing out showers of red hot stones and enormous volumes of smoke In 1803, it was exploding every ten minutes, ejecting each time a column of smoke Along the western or Iranian arc is the extinct Koh-i-Sultan in Baluchistan It is in a solfataric stage giving out sulphuretted hydrogen and other sulphurous gases

India and Pakistan, though not now troubled by volcanic activity, have certain areas, particularly those bordering the junction between the Indo-Gangetic plains and the extra-peninsular mountains, that have been the scenes of earthquakes with disastrous effects This is a zone of great tectonic strain, having long parallel fractures indicating the position of the mountain at each recurring uplift

CHAPTER NINETEEN

THE QUATERNARY PERIOD — III

Plant Life

Considerable factual information about plant life during the Quaternary has been obtained in Europe, North America and Japan, and some from Africa and South America. Much of this information reveals that the Quaternary vegetation was not much different from the present in these regions, but for some of the early Quaternary genera which are now extinct. The successive shifts in the plant populations in response to climatic changes gradually resulted in the present pattern of plant life.

Europe and America

At the commencement of the Ice Age, some Tertiary elements continued to exist during the early part of the Quaternary in Europe, which gradually disappeared during the mid-Pleistocene. Statistically it has been observed that a considerable decline, from 24 to 16 per cent, of such elements took place from the Pliocene to early Pleistocene, the important lingering genera being *Pterocarya*, *Careya*, *Engelhardtia*, etc.

The present climatic zones of Europe are: the outer, comprising north of the Alps, Carpathians and Pyrenees; the inner, comprising south-east of these mountains including Bulgaria and Rumania; and the southern, the Mediterranean region, which had already been established during the Miocene. At the beginning of the Pliocene, the North American element declined considerably and there was a large rise in the east Asiatic element. The europeanization of the flora in the outer zone took place during the Pleistocene. The major change was the replacement of evergreen element by the temperate deciduous forest types. The east Asiatic element completely vanished from the outer zone during the catastrophic climatic changes in the Glacial Epoch. During the warmer interglacials, the southern or south-eastern or some old North American elements surviving in the southern zone, invaded the outer zone, but were again pushed back during the next glaciation. Thus, it was mostly the north-south or vice versa movement of the flora in Europe during the Quaternary. More or less similar floristic movements occurred in North America.

Despite the extensive ice sheets, refugia or nunataks existed where the plants survived

during periods of severest cold, to invade areas freed from ice, with the improvement of climate During an interglacial, a definite climatic cycle produced important shifts in plant populations, the sub-arctic flora comprising dwarf willows, arctic birch and *Dryas octopetala* gave place to forests of temperate birches, pine and aspen which were later invaded by broad-leaved deciduous oak forests including alder, oak, elm and hazel Oak forests were then replaced by hornbeam, spruce and pine, and later by pine, birch, aspen, and spruce, until the sub-arctic vegetation, comprising arctic birch etc again returned. During successive climatic and vegetational changes in the various glacial and interglacial phases, some species became extinct from Britain, such as *Corema intermedia*, *Picea abies*, *Trapa natans*, *Najas minor*, *Salix polaris*, *Azolla filiculoides* etc although a few reappeared later In other European interglacials, some North American plants such as *Tsuga*, *Thuja*, *Brasenia purpurea*, *Dulichium spathaceum* and *Taxodium* still persisted. During the interglacials the composition of the mixed oak woods was also sometimes different, as during the Eemian in England it was dominated by hornbeam The vine, *Vitis sylvestris*, and *Rhododendron ponticum* which no longer grow in the Inn valley grew there in the Mindel/Riss interglacial During the Ice Age, the conifers migrated far south through North America *Picea glauca* and *P mariana*, which today grow further north and around Lake Huron, flourished in Texas during the last glaciation, and both *Picea* and *Abies* grew in Florida

The Holocene, after the last glaciation, commenced with the sub-arctic flora representing the open tundra-like vegetation comprising *Salix herbacea*, *Dryas octopetala*, *Betula nana*, etc This late glacial phase was followed by birch (*Betula pubescens*) forest and later by pine or by birch-pine forest This subsequently was replaced by pine and mixed oak woods approaching beech forest or beech-oak-hornbeam or alder-oak-elm-birch-beech zone The late glacial phase in North America has now been observed and the post-glacial succession there is from spruce-fir, pine, oak-hemlock and oak-hickory to oak-chestnut-spruce

The vegetation came under the influence of man during the post-glacial climatic optimum when the Neolithic man commenced agriculture Although much of the migrations of weeds took place during glacial and sub-arctic phases, some of them were diffused by the migrating Neolithic folk through the practice of agriculture Several of the weeds today associated with agriculture may be attributed to them Of these, *Plantago lanceolata*, white man's foot print as it is called, is believed to have been introduced by man in America Late historical introductions by man have been many

India

There is little, if any, factual information on Quaternary plant life in India. The

Pleistocene and post-glacial deposits in Kashmir have yielded some information showing that the Quaternary plant life in the valley was much like the present in the western Himalayas. The uplift of the Pir Panjal cut off the valley from its southern part depriving it of the benefit of the monsoon. This climatic change in the valley resulted in the decline of certain elements, e.g., oaks and alders. They continued to exist until exterminated recently from there, very likely by man. Before the Glacial Epoch and rise of Pir Panjal had begun, the east Himalayan larch and *Engelhardtia* and even the Nepalese alder, which today do not extend beyond Kumaon, grew in the Kashmir valley. They became extinct after the second glaciation which was the severest of all.

In the absence of any other factual data, some aspects of floristic changes in the country during the Quaternary can be built up from the climatic and geographical relationships of modern Indian flora.

Decline of tropical rain forest. Not much is known of late Tertiary plant life in India. The presence of palms and Guttiferae suggests the occurrence of tropical rain forest during the Miocene at Kasauli in the north-west Himalayas. Fossils of *Anisoptera* (Dipterocarpaceae), a genus today restricted to the rain forests in Assam and Burma, from the Miocene deposits near Jawalamukhi, further support the occurrence of tropical rain forest in north-west Himalayas. During earlier periods, Eocene for instance, evergreen forest existed in the present Rajasthan. Evergreen rain forest, which is today confined to the Western Ghats and Assam in India, is thus an ancient relic.

The evergreen rain forests in the Western Ghats and Assam have much in common and also with the flora of Burma and Malaya. The cumulative effect of the Quaternary climatic and edaphic changes has reduced these forests to their present restricted distribution along Malabar coast and Assam. These forests now exist in the narrow belt of the country over 80 km broad in Western Ghats from Goa to Cape Comorin through Kanara and Coorg to highlands of Kerala in the south and parts of Madras State towards the east. In drier parts, teak woods and sandal woods occur in these regions. The higher mountains are populated by species of *Ternstroemia, Microtropis, Michelia, Gordonia, Syzygium, Photinia, Rhododendron*, etc. with shrubs of Oleaceae, Rubiaceae, Rutaceae and various climbers and lianas. The patches of the forests in the ravines are called the sholas (Pl. 79). Since the region is characterized by high humidity and abundant rainfall, it is in fact the Pluvial flora which had advanced and retreated during the Pluvial and interpluvial periods in the peninsular India and in Assam. Successive fluctuations must have occurred between the wet-evergreen and the dry-deciduous forests until their present distribution was attained. An interesting result of the Quaternary events and changes in climate is

the reduction of the shola forest in the Nilgiris to the status of a living fossil community for which the present environment is so inimical that it has stopped regenerating itself Any injury to the shola forest is a permanent injury from which it never recovers

The alternations in the climatic patterns obtained during the Quaternary pushed the tropical humid forests comprising Orchidaceae, Scitamineae, Zingiberaceae, Xyridaceae, Palmae, Pandanaceae, Piperaceae, *Chloranthus*, *Artocarpus* and *Ficus*, Araliaceae, Apocynaceae, shrubby Rubiaceae, Rutaceae, *Garcinia*, Annonaceae, nutmegs, Dipterocarpaceae, Meliaceae and Myrtaceae to the south and east Many of these are sensitive to cold. Some of the tropical plants indifferent to cold have continued to advance to the base of the N W Himalayas and these are *Bauhinia*, *Acacia*, *Erythrina*, *Butea*, *Dalbergia*, *Millettia* and other Leguminosae, *Salmalia*, *Vatica*, *Nauclea*, Combretaceae, Verbenaceae, Lagerstroemias, Grisleas, Jasmines and Bignonias

Invasions by the western element. The movement of the evergreen rain forest towards the east and the south was accompanied by the invasion of Mediterranean element from the west This largely comprised the species distributed in Egypt, southern Arabia and the warmer parts of Persia and even some members growing in other parts of Africa Many plants from these regions invaded India through Baluchistan, Sind and Punjab In the upland regions of the rising Himalayas, *Pinus roxburghii*, *P gerardiana* and *Cedrus*, extending today from Afghanistan, and species of *Juniperus* together with some broad-leaved genera, such as *Populus*, were perhaps the arrivals during the Pliocene and Pleistocene

There are several genera and families in the Peninsula which are also found in the mountains of west tropical Africa, such as *Stephania*, *Grewia*, *Hippocratea*, *Impatiens*, *Zizyphus*, *Anogeissus*, *Blumea*, *Jasminum*, *Torenia*, Euphorbiaceae, Leguminosae, Rubiaceae, Asclepiadaceae, Acanthaceae, etc *Delphinium dasycaulon* is found in Abyssinia as well as in the mountains of Deccan *Pterolobium indicum*, *Trema amboinensis*, *Antidesma ghesaembilla* and *Celtis australis* are comparable with the species of respective genera in Abyssinia Some of these may have arrived in the mid and late Tertiary, but many of them may have entered the country during the Quaternary

Many of the herbs in the desert and arid regions which had come from as far as Arabian and African deserts include *Peganum harmala*, *Fagonia cretica*, *Balanites aegyptiaca*, *Acacia arabica*, *Alhagi*, *Grangea*, *Calotropis*, *Salvadora persica*, *Malcolmia*, *Farsetia*, *Cleome*, *Balsamodendron*, *Astragalus hamosus*, *Cucumis*, *Colocynthis*, *Pluchea*, *Anticharis*, spinous Acanthaceae, *Cometes*, *Forskohlea*, *Populus euphratica*, *Ephedra*, etc. Some of these are now widely distributed in north-west of India.

Courtesy FRI Dehra Dun

SHOLA FORESTS IN THE NILGIRIS

Shola forests are a living fossil community limited to the hollows especially the heads of water courses. Once destroyed they do not regenerate

Several of the other arrivals spring up in the rainy season such as *Cleome*, *Gynandropsis*, *Urena*, *Sida*, *Melochia*, *Corchorus*, *Triumfetta*, *Aeschynomene*, *Smithia*, *Indigofera*, *Dolichos*, Cucurbits, *Blumea*, *Vernonia cinerea*, *Exacum*, *Scrophularia*, *Leucas*, *Ocimum*, *Hedychium*, *Gloriosa*, Commelinaceae, grasses and sedges, *Capparis*, *Grewia*, Sterculiaceae, Tiliaceae, columnar Euphorbias and other members of Euphorbiaceae, Olacineae, Acacias and Rubiaceae. The Holocene forest clearances and the early agricultural practices played a large part in their spread throughout the country.

Influx from the north. Mention has already been made of the invasion of some Mediterranean element in the Himalayas towards the earlier phases of the Pleistocene when oaks and alders together with *Cedrus* clothed the mountain ranges. The commencement of the glaciation and its successive repetitions introduced the Siberian, the European, and some Chinese forms in the north-west Himalayas, and Japanese and Chinese elements in the eastern Himalayas. The present alpine flora is largely constituted by this assemblage. The dominance of Fumariaceae, Potentillas, Leguminosae (*Hedysarum* and *Astragalus*), Umbelliferae, *Lonicera*, *Artemisia*, *Pedicularis*, Boraginaceae and *Hippophae* are the typical examples which approach the south European vegetation. To this list may also be added members of Nymphaeaceae, Caryophyllaceae, Hypericaceae, Geraniaceae, Leguminosae, Rosaceae, Lythraceae, Crassulaceae, Rubiaceae and Compositae. Special mention may be made of *Nymphaea alba*, *Marrubium vulgare*, *Nepeta cataria*, *Potentilla reptens*, *Trifolium fragiferum*, *Crataegus oxyacantha*, *Rubus fruticosus* and *Aquilegia vulgaris* most of which are concentrated in the extreme west, but the last extends up to the Kumaon hills.

Likewise, the Chinese and Japanese element was largely concentrated in Sikkim, Bhutan and Khasi hills in Assam, a few species extending westwards to Garhwal and Kumaon. The Sino-Japanese element includes species of *Aucuba*, *Helwingia*, *Stachyurus*, *Enkianthus*, *Abelia*, *Skimmia*, *Bucklandia*, *Dichroa*, *Benthamia*, *Corylopsis*, etc. Other plants common between China, Japan and the eastern Himalayas are *Microptelea parvifolia*, *Hamamelis chinensis*, *Nymphaea pygmaea*, *Vaccinium bracteatum*, and *Quercus serrata*. The Chinese genera that were pushed into the eastern Himalayas include *Illicium*, *Magnolia*, members of Schizandraceae, *Camellia*, *Deutzia*, *Hydrangea*, Cornaceae and *Houttuynia*. A Japanese and Chinese family, Lardizabalaceae, attains maximum development in the eastern Himalayas.

A few American elements such as *Adenocaulon*, *Oxybaphus*, *Podophyllum*, *Meconopsis* (sect. *Stylophorum*), *Gnetum*, *Lardizabala*, *Monotropa uniflora*, *Brasenia* and *Mitreola paniculata* perhaps also arrived through the eastern Himalayas. In view of the fortune

relationship between eastern Asia and western America during the Tertiary, their advent into India during that period seems probable.

Diffusion of the new arrivals. Successive climatic changes during the glacial and interglacial stages caused considerable shifts in floral populations, so that some elements of the east are found in the west, and of the north in the south, and vice versa The sub-tropical transitional belt between the temperate and tropical vegetation, and the admixture of eastern Himalayan and western Himalayan floras in Nepal came into existence *Osbeckia, Argostemma, Plectranthus*, members of Cyrtandreae, Scitamineae, Araceae, Commelinaceae and Orchids advanced northward and are present today even on lofty mountains The glacial periods drove the extra-tropical weeds from the north temperate regions to South India and these include species of *Ranunculus*, Cruciferae, Caryophyllaceae, members of Papilionaceae, *Gnaphalium, Xanthium, Veronica, Anagallis*, species of *Heliotropium, Polygonum, Juncus bufonius, Butomus umbellatus, Alisma plantago*, Cyperaceae and Gramineae, *Myriophyllum, Potamogeton, Vallisneria, Zannichelia*, etc Several Siberian plants like *Spiraea kamtschatica, Paris polyphylla* and *Corydalis sibirica* have come to stay in the rainy Himalayas The floristic migrations from the south to north have not been without impact on the vegetation of Siberia, the tropical *Menispermum* still occurs there Although the oaks and pines could not descend below the foothills of the Himalayan chain, quite a few arrivals from Europe into the Himalayas were pushed into the south Indian hill stations where they find refuge today after the climatic patterns have changed. These include *Stellaria uliginosa, Circaea alpina, Sanicula europaea, Brunella vulgaris, Thallictrum, Ranunculus, Cardamine, Geranium, Alchemilla, Fragaria, Potentilla, Parnassia, Ajuga* and Cyperaceae and Gramineae

Some typically Himalayan species of *Berberis, Hypericum, Rubus, Pedicularis* and *Rhododendron* found in the south Indian hills migrated there during the Glacial Epoch It was during the Quaternary that the alpine belt of Europe extended to the high peaks of the Himalayas above the tree limit, where today several foreign types such as species of *Gentiana, Ephedra, Corydalis* and members of Valerianaceae are found

Despite such a vast change in the floristic pattern of India, quite a few temperate genera such as *Erica, Arbutus, Azalea, Fagus, Cochlearia, Tilia, Lupinus, Rhinanthus* and *Empetrum*, and Cistaceae seem to have failed to reach the sub-continent Some, like *Hieracium, Trifolium, Centaurea, Veronica* and *Dianthus*, which, however, reached here did not multiply and only a few species are found They are perhaps introduced by man and have been associated with agriculture Some genera from other parts of the world have found so congenial an environment in the Himalayas that they have attained maximum

development These are *Rhododendron*, *Monotropa*, *Pedicularis*, *Corydalis*, *Nepeta*, *Carex*, *Spiraea*, *Primula*, *Cerasus*, *Lonicera*, *Viburnum* and *Saussurea*

Adaptations. Local and regional differences produced as a result of successive alterations in the climatic belts have resulted in disjunct distribution of once widely distributed plant communities and individual plant species Their confinement to local and regional environments resulted in new forms, the ecoforms, and eventually in new species It is believed that *Cedrus* had a continuous distribution at lower levels from Lebanon to India during the Quaternary and the disjunct distribution resulting from Quaternary events has evolved three distinct races or sub-species now recognized as Lebanon Algerian, and Deodar cedars

The changes in climate and physiography not only changed the pattern and composition of plant life in the country but it also resulted in considerable variations in individuals of the same species as regards habit, habitat, colour of flower, leaves odour and hairiness *Pinus roxburghii* grows well in the climate of Kumaon, Nepal and Sikkim but is stunted on the sandstone rocks in the arid parts of the Punjab hills The high and low level forms of *Pinus wallichiana* and silver firs, the adaptability of *Cedrus deodara* to both moist and dry habitats the variable growth of *Taxus baccata*—tall in the deep forest, lax, prostrate and bushy along the edge of the forest, and stout dense and horizontally branched in he open, and *Ephedra* sp with 60 cm high plants in the plains and hardly 2 5 cm long at 4500 m altitude are other examples Similar variable forms are seen in *Rosa*, *Spiraea*, *Berberis* *Juniperus*, *Sarcococca*, *Hippophae* and *Myricaria* The trees of *Shorea robusta* are gnarled in dry regions but are robust in the Terai forests Cassias, Indigoferas and species of *Alysicarpus* are tall, slender and delicate in the moist regions but prostrate and wiry in drier habitats

Influence of man. With the introduction of agriculture in the Neolithic, man began to exercise considerable influence on the plant life in India, as elsewhere Together with several introduced crops into this predominantly rice growing region came along several weeds associated with cultivation With the growing population and increasing demand on the forests for clearance of land for cultivation, for smelting copper and later iron for baking bricks and pottery, a tremendous destructive influence in addition to climatic and edaphic changes, reduced the indigenous forests to a great extent The flourishing vegetation in Rajasthan and Sind was replaced by a desert about a couple of thousand years ago

CHAPTER TWENTY

THE QUATERNARY PERIOD — IV

Animal Life

The marine fauna of the Pleistocene shows little difference from that of the present day Extinct forms are very rare and are mostly reduced to varietal forms of the living species The distribution of the fauna in the north was, however, different There was displacement and migration as the ice-sheets advanced and retreated. One reason for lack of many new or different forms is the shortness of the epoch, a million years, a period too short to produce any significant change.

The faunas of the Quaternary Period were influenced by the migrations brought about as a result of climatic changes Many mammals moved between Eurasia and North America by way of the Bering Strait 'filter bridge', and between North and South America by way of the Panama bridge Camels and horses migrated from North America to Eurasia while mammoths, bisons and stags migrated from Asia to North America Pumas, raccoons, mastodons and horses migrated from North America to South America Ground sloths glyptodonts (Pl 80) and porcupines migrated from South America to North America The rhinoceroses and pigs remained confined to Asia and the pronghorns and peccaries to North America

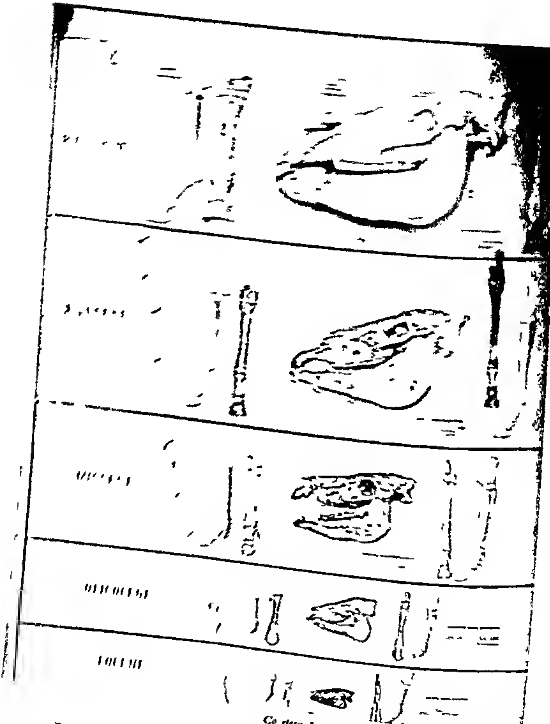
Corresponding to glacial and interglacial stages, a succession of mammalian faunas can be noticed in the Pleistocene An early fauna, called warm fauna essentially characterized by *Elephas antiquus* marks the beginning of the Pleistocene Along with *Elephas antiquus* was found *Rhinoceros mercki* also extinct, and more rarely *Hippopotamus major*, closely allied to the living *Hippopotamus amphibius* The most typical members of the succeeding cold fauna were *Elephas primigenius* and the woolly rhinoceros, *Rhinoceros tichorhinus*, both now extinct Occasionally, the musk ox *Ovibos moschatus*, of Greenland and North America, and the reindeer, *Rangifer tarandus*, were also present.

The asphalt deposits of the Rancho La Brea in Los Angeles, United States, are famous for fossil Pleistocene mammals and birds which were discovered while digging for asphalt It is estimated that about three million fossil bones have been recovered. Among the animals found are: sabre-toothed tiger, lions exceeding in size, all living and extinct

Painting Charles R. Knight. Courtesy American Museum of Natural History, New York

PAMPEAN LIFE OF ARGENTINA DURING THE GLACIAL EPOCH OF THE NORTHERN HEMISPHERE

Giant ground sloth left foreground Toxodonts left background Glyptodonts right foreground and Macrauchenia right background based on Cape Pampean collection



Courtesy American Museum of Natural History, New York

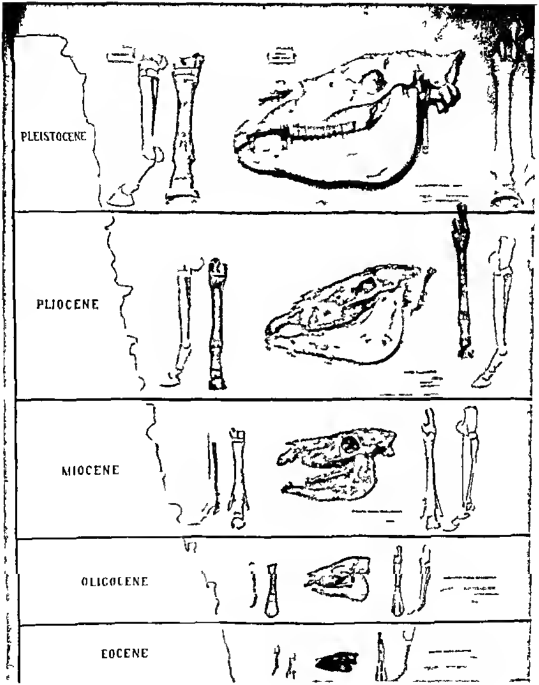
EVOLUTION OF THE HORSE—SKULLS AND FEET

forms; huge wolves, probably the largest of the tribe, cats, distinct from any living type; ground-living sloths of the size of rhinoceros; mastodons, camels, deer, antelopes, rabbits, hares and mice, eagle-like bird, larger than the condor, and kites, hawks, and owls These animals belonged to the Glacial Epoch, flourished at least one hundred thousand years ago, and were entombed in the asphalt-tar swamps in a curious way In a diary, written during the first Spanish expedition to California, it was reported that the asphalt flowed in swamps like melted rock from underneath the ground. It was, therefore, originally an oil seepage turned to tar and asphalt through loss of its volatile materials Probably, the animals unsuspectingly, came to drink water that was underlain by tar and stuck in the swamp and sank Their corpses attracted predatory mammals and birds who also eventually sank and became victims of the pool (Pl 81)

Evolution of Some Important Mammals

Apart from the emergence of man, Pleistocene witnessed the arrival of the elephant, horse, camel and rhinoceros. The first three of these animals served as food for man in the hunting stage, and later were used by him for transport

The gradation in foot, teeth and skull structures of horses, elephants, and camels through different levels of the Tertiary deposits indicates not merely taxonomic series but actual descent lines under varying environmental conditions During the Oligocene, there was heavy rainfall and forests developed over most of the land. The ungulates, the hoofed mammals with cloven feet, adapted for life in marshy or soft ground, flourished. Their teeth were fitted for chewing the soft leaves of the trees and browsing on the succulent undergrowth With the advent of the Miocene, seas began to retreat, and rainfall decreased. The forests were decimated, and the grasses spread over wide areas The teeth of the ungulates now became adapted for chewing grasses, and the feet for life on the grassy plains There came corresponding changes in the limbs which became slim and helped in running It is thus that these animals saved themselves from the carnivores



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EVOLUTION OF THE HORSE—SKULLS AND FEET

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Forests gradually gave place to open plains over large areas in North America, and Eurasia Since there were no shrubs for concealment, an animal had to run fast to survive. Its teeth had to be strong to chew tough grasses *Pliohippus* and *Hipparion* of the Pliocene were much like *Merychippus*, but bigger and with more complex teeth Both *Merychippus* and *Pliohippus* had three toes on each foot but used only the middle one As the side toes became useless on hard ground, they began disappearing In *Pliohippus*, the side toes were not outwardly visible *Equus*, or true horses, appeared in the Pleistocene Their side toes were reduced to mere fragments or splints of bones, while the middle toe hardened into a large tough hoof, characteristic of the modern horse The single toe, the long, slender leg bones, and the fusion of tibia and tarsus in the modern horse indicate adaptation for speed on hard ground. The teeth also became adapted for chewing the grasses that grow in the plains

Evolution of the horse is shown in Pl 82 Several thousands of specimens of various stages have been discovered. Over 260 species have been recorded, which merge into one another Link after link has been established, and we are now able to reconstruct the pedigree of horse for over forty million years

A strange fact about the horses is that although North America was the centre of their origin, they spread into eastern hemisphere in the Miocene and became extinct in North America in the Pleistocene They were re-introduced in North and South America by the early Spaniards In South America they multiplied and ran wild in large herds over the pampas The genus *Equus* at present includes seven species—the Przewalsky's horse from Central Asia, the wild stock of the present horse, three species of zebras from Africa, and three wild asses, two from Asia, and one from Africa. In addition, there are many varieties of domestic horse and donkey, the result of man's selective breeding

Elephant Fossil elephants exhibit gradation from a pig-like animal known as *Moeritherium*, from the Eocene of Egypt, to four-tusked and subsequently to modern elephants with two large tusks The trunk evolved from the prolongation of the upper lip

Moeritherium had neither tusks nor trunk Its upper lip was, however, elongated like that of a tapir, and the second upper and lower incisors were enlarged and bent forward. A diversification of types began with the advent of the Oligocene In *Palaeomastodon* of the Oligocene, the elongation of the pre-nasal and symphysial regions of the skull became noticeable while there was a shortening and elevation of the post-nasal portion Though the large upper incisors were tusk-like, they still showed a downward curvature The lower jaw had also a pair of small tusks

The next stage of evolution is seen in *Tetrabelodon*, also called *Trilophodon* In the

earlier species of this genus from mid-Miocene to Pliocene, the symphysial region of the lower jaw grew so long that the tusk-like incisors could not easily reach the ground during food collection. The prehensile nose, therefore, lengthened beyond the tips of the tusks, forming the trunk, which served to collect vegetation and to suck up water. In the later species, further evolution led to the rapid shortening of the symphysial region, straightening of the tusks and the union of the cusps on the molars to form transverse ridges It was during the *Tetrabelodon* stage of evolution that the elephants, so long confined to Africa, migrated to Europe and Asia By the middle of Miocene, they reached North America by the land bridge across the Bering Strait.

In the Pliocene, the ancestors of true elephants appeared with curved upper tusks, short tuskless lower jaw, and greatly expanded molars with numerous low crests In early Pleistocene, true elephants had simple molars High-crowned teeth evolved later in the epoch. It was during the Pleistocene that the elephants reached their maximum development.

The early Pleistocene true elephants continued to have the low-crowned teeth of their ancestors. They were known by the generic name *Mammuthus* or commonly mammoths, now assigned to *Elephas*. Their tusks first grew downwards, then arched forward to become very large. They had a rapid evolution within a period of less than a million years and spread practically all over the world and died out in the severe cold of the later part of the epoch. They were about the size of the living Indian elephant to which they are also related, and differ from it in having a coat of grey wool covered by long coarse brown hair, which protected them against the arctic cold (Pl. 83). Frozen bodies, complete with hair, skin and dried blood, have been found in Siberia and Alaska. Man and the mammoth were contemporaries during the Pleistocene. Paintings of these mammoths made by man are found on the walls of pre-historic caves in France. Carvings on the ivory of mammoths are also known. Asiatic elephant is a descendant of the early mammoth. Its tusks are directed downwards, and molars are high and broad. The last molars may have as many as twenty-four closely folded crossplates. The evolution of the elephant family is shown in Pl. 84.

Camel. Like the horse, the camel evolved in North America but is now confined to North Africa and Asia. The related llamas of South America evolved in the Pleistocene. The earliest known camel is *Protylopus* of the upper Eocene. It was a small creature with forty-four teeth, the canines being slightly elongated and all the molars were low-crowned. It had four toes but the lateral ones were embryonic and the metapodials were not united.

During the Oligocene, the camels became diversified through varied adaptations and the two-toed pattern of the feet became firmly established. *Poebrotherium* resembled

its contemporary *Mesohippus* in the degree of evolution It grew up to the size of a sheep but had relatively longer limbs and neck, and a tapering skull The digits, in all the limbs were reduced, and the side toes did not develop beyond the embryonic stage. During the Miocene, as in the earlier times, both the camels and the horses lived practically under the same climatic conditions when grasslands were widespread. The evolution of the camels and the horses again shows parallel development From the grazing camels, which included the lower Miocene *Protomeryx* and the upper Miocene *Procamelus*, evolved modern camels *Protomeryx* still had the full set of teeth but the grinders were adopted for chewing hard grass The two-toed feet had pointed hoofs like those of the deer The reduction of teeth occurred first in *Procamelus* In this genus, the first and second incisors were lost and were replaced by a horny pad Adaptation to desert conditions led to the development of padded foot The hump of the modern camels is, however, a recent development

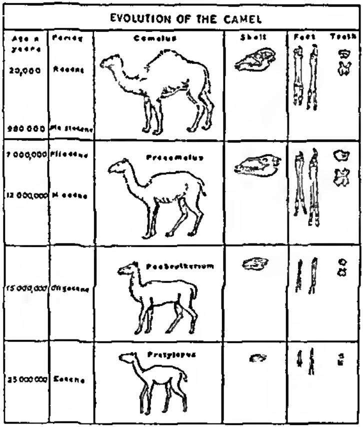
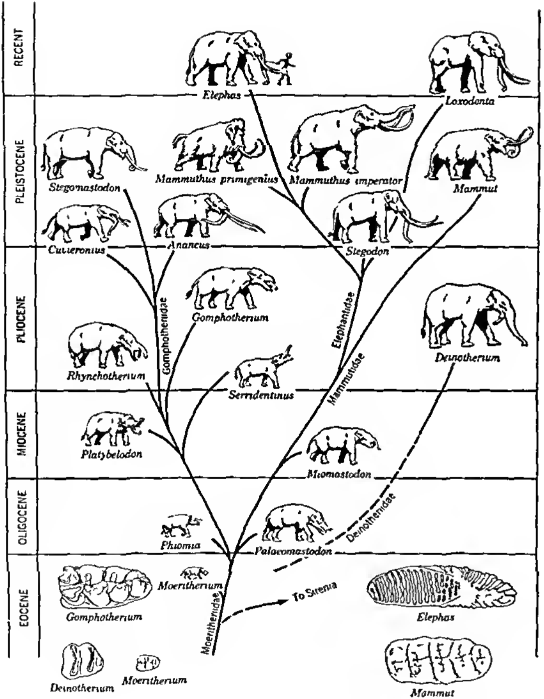


Fig 72. Evolution of the camel

Mural Charles R Knight Courtesy American Museum of Natural History New York

WOOLLY MAMMOTH RIVER SOMME FRANCE

There elephants existed from the Pleistocene upto 15 000 years ago in the European and Asiatic tundra



Courtesy American Museum of Natural History, New York

EVOLUTION OF THE ELEPHANT FAMILY

In addition to other changes from *Protylopus* and *Procamelus* to the modern camels, there has been a progressive elongation of the metapodials, and their close union to form the cannon bone The dentition, which was full and continuous, gradually lost the upper incisors, and developed a wide gap, the diastema, in front of premolars, a characteristic of all vegetable feeders The evolution of the camel is shown in Fig. 72.

Rhinoceros. The living rhinoceroses are remnants of a once widespread and abundant group There are now only three species in Asia and two in Africa, and they seem to be heading for extinction. The rhinoceroses arose from small animals, slightly bigger than *Eohippus*, in the Eocene. They had four toes on the forefeet and three on the hind feet, and long slender legs for running The teeth were low-crowned, adapted for browsing Several groups of such Eocene rhinoceroses disappeared by the Oligocene. One

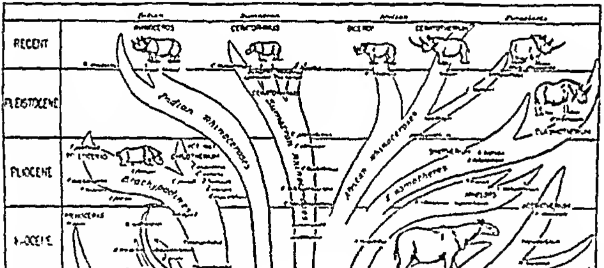


FIG. 73 EVOLUTION OF THE RHINOCEROS FAMILY Reconstruction of the fossil remains of the Tertiary and Quaternary Periods (After Henry Fairfield Osborn Courtesy American Museum of Natural History New York)

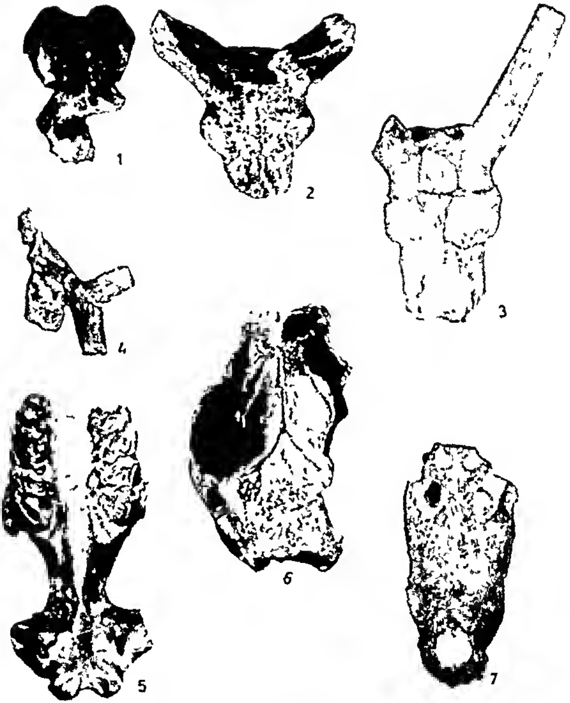
group seems to have adapted a mode of living similar to that of the present day hippopotamus Another evolutionary stock of rhinoceroses led to the development of *Baluchitherium* We have already made a reference to this gigantic animal It was a hornless rhinoceros that lived in Mongolia, Baluchistan and southern Russia during the Oligocene and Miocene Epochs During the Miocene and subsequent times, various one- and two-horned rhinoceroses evolved which began declining during the Pliocene and the Pleistocene The evolution of the rhinoceroses is shown in Fig 73 A contemporary of pre-historic man was the huge woolly rhinoceros known as *Rhinoceros tichorhinus* It lived in Europe during the last Ice Age and like the mammoth had a protective coat of thick hair It became extinct with the passage of the Ice Age

Bovidae The most familiar ruminants, such as sheep, goats, musk oxen, antelopes and cattle appeared in the Miocene, but it was not until the Pliocene that they became diversified Today they are the most abundant among the mammals and occur in a great variety of forms The greater part of their evolution took place in Eurasia and Africa In early Bovidae, the horns were slender and straight, and were close together almost between the eyes, a feature still persisting among the living antelopes One line of evolution led to the elongation and widening of the frontal bone which finally resulted in the separation and backward shifting of the horns This progressive change is found maximum in the oxen The sheep and antelopes first appeared in the upper Miocene and the oxen and goats in the Pliocene

Some Important Pleistocene Animal Fossils from India

In the Boulder Conglomerate, the highest horizon of the Siwalik system and referable to the lower Pleistocene, modern ox, camel and horse make their first appearance, while *Stegodon ganesa* (Fig 74), *Rhinoceros, Hippopotamus, Sivatherium, Hyaena* and *Felis* are the survivors from previous faunas Some of the fossil animal skulls recovered from the upper Siwaliks at Pinjor, near Chandigarh, are given in Pl 85 Fig 75 shows the horns of *Bos acutifrons,* an extinct relative of the buffalo and Fig 76 the restoration of *Colossochelys atlas,* a giant tortoise Both these animals lived in the Siwaliks of Punjab during Pleistocene A fauna consisting of *Elephas antiquus* and *Equus namadicus* with extinct species of *Rhinoceros, Hippopotamus, Cervus, Bos, Sus,* etc has been found in the middle Pleistocene alluvium of the Narmada valley

Vertebrate bones of the middle Pleistocene age are sometimes found in the Godavari valley One of the species identified is the gigantic *Elephas antiquus* (*namadicus*) with thick and long tusks The circumference of a tusk measured 75 cm at its proximal end The animal must have been about five metres in height



Courtesy Geology Dept., Panjab University, Chandigarh

FOSSILS OF ANIMAL SKULLS RECOVERED FROM THE UPPER SIWALIKS AT PINJOR NEAR CHANDIGARH

1. *Hypselephas hysudricus* 2. *Hemibos triquetricornis* 3. *Hemibos antelopinus* 4. *Cervus punjabiensis* 5. *Elephas [illegible]* 6. *[illegible]* 7. *[illegible]*

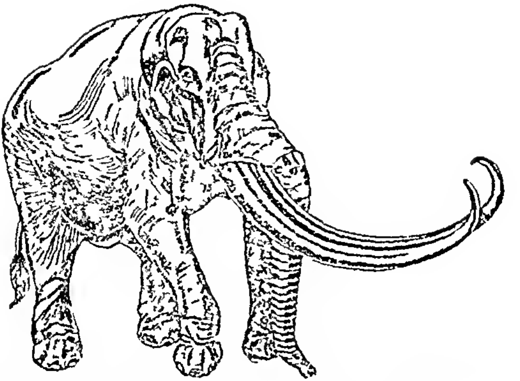


FIG 74 RESTORATION OF *Stegodon ganesa* A GIANT EXTINCT ELEPHANT WITH TUSKS OCCASIONALLY MEASURING OVER 4 m. IN LENGTH The species lived in the Punjab and Jammu region during the upper Siwalik times. Its remains have also been found in the middle Pleistocene alluvial deposits of the Narmada valley in South India

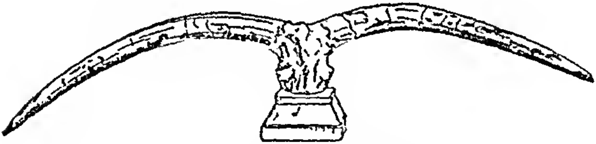


FIG. 75 [illegible] AN EXTINCT RELATIVE OF MODERN BUFFALO WITH HORNS MEASURING OVER 2 m. END TO END FROM THE UPPER SIWALIKS OF THE PUNJAB (Pinjor stage)

From the upper drainage area of the Krishna, teeth of *Mastodon pandionis* have been found. Portions of the cranium and mandible of *Rhinoceros deccanensis* and remains of an undetermined bovine have been obtained from the bank of Ghataprabha near the town of Gokak in Mysore State. Large number of chipped quartzite of the same type as those discovered in the Narmada alluvium have also been found in the gravel deposits of southern Maharashtra. But the relations between the ossiferous gravels and those containing the implements are not well understood.

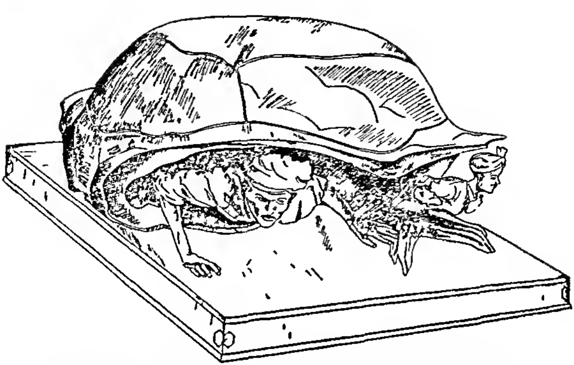


FIG 76. RESTORATION OF *Colossochelys atlas* ABOUT 2.4 m LONG GIANT TORTOISE WHICH LIVED IN THE SIWALIK REGION OF THE PUNJAB DURING THE PLEISTOCENE Its enormous skeleton can accommodate two persons

In the Narmada valley between Hoshangabad and Narsinghpur, there are old river terraces rising some 36 m above the stream Mammalian bones have been found from the base of upper gravel and sand, equivalent to the Potwar silt, while pre-historic implements have been discovered abundantly in the layers of gravel Animal fossils found include the following

LAMELLIBRANCHIATA

Unio corrugatus Lam var and *Corbicula* aff *striatella*

GASTROPODA

Viviparus (*Paludina*) *bengalensis* Lam.

REPTILIA

Pangshura tecta Bell (*P flaviventris* or *Emys namadicus* Theob, found in Indian rivers today)

MAMMALIA

Ursus (*Helarctos*) *namadicus* Falc & Cautl

Bubalus (? *Buffelus*) *palaeindicus* Falc. (allied to the modern Indian buffalo)
Boselaphus namadicus Rut. (related to the modern 'blue bull' or *nilgai*, *B. tragocamelus*)
Bos namadicus (from the Siwaliks)
Cervus duvaucelli Cuv. (allied to the modern *barasingha*)
Sus namadicus Pilg.
Hippopotamus palaeindicus Falc. & Cautl. (belonging to a sub-genus now only found in Africa)
Hippopotamus namadicus Falc. & Cautl. (probably from an earlier Siwalik ancestor)
Equus namadicus Falc. & Cautl. (from the Siwaliks)
Rhinoceros unicornis Linn. (a living species)
Elephas antiquus (*namadicus*) Falc. & Cautl. (probably identical with the European, *E. antiquus*)
Stegodon insignis Falc. & Cautl. (Siwalik species)
Stegodon ganesa Falc. & Cautl.

The fauna appears to be middle Pleistocene, and equivalent to that of the Boulder Conglomerate stage of the Siwalik. One of the palaeolithic implements found is a chipped stone scraper or hatchet discovered near Bhutra, eight miles north of Gadawara.

Cave Fauna

In peninsular India, from Billa Surgan, a few kilometres north of Banganappalli in the Kurnool district of Andhra Pradesh, ossiferous cave deposits have been found. The caves are in the limestones. Their floor is encrusted with stalagmite, beneath which lies a red marl full of animal bones, some of them showing traces of having been shaped by man. The fauna includes apes, several carnivores, one insectivore, bats, rodents, ungulates, an edentate, several birds and reptiles, toads and molluscs. It comprises many recent forms and others closely allied to living forms, but extinct. The most interesting feature of the fauna is the occurrence of four forms which are identical with, or closely allied to living African types. These are a species of the ape, *Cynocephalus*, the wild ass *Equus asinus*, a species of *Crocuta*, probably identical with one found in the Pleistocene alluvium of Tiruchirapalli, and an edentate apparently identical with the west African *Manis gigantea*. The age of the extinct fauna is regarded as upper Pleistocene.

Extinction of Large Mammals

As the close of the Cretaceous saw the extinction of dinosaurs and the rise of the mammals so the end of the Pleistocene saw the extermination of large mammals and the rise of man. The reason for the wide extermination is not definitely known. Pleistocene

conditions were at times extremely severe for plant and animal life in the northern hemisphere The great Antarctic and Greenland ice caps are practically without life It is, therefore, reasonable to assume that four advances of glaciers in the northern hemisphere drove the flora and fauna to the south totally depopulating the areas over which the glaciers moved The retreats of the glaciers allowed life to spread over again in the north But each advance of glaciers caused widespread extinctions and replacements Many large and heavy animals had become highly specialized and suffered from shortage of food to which they were accustomed, or became victims of epidemics Still others were exterminated at the hands of progressive and vigorous invaders through land connections between continents

Man himself has been responsible for the destruction of many giant animals, not so much directly, but by burning forests But primitive men living in small communities could not have greatly affected animals so large, numerous, and well established as were the mammoths and mastodons Thus, we may only speculate the causes of their extinction, and one of them may be over-specialization Specialization once started continues until the limit is reached and thence begins slow degeneration of organs or rapid extinction of individuals

Extermination of life is going on even at present The Asiatic or Indian lion, immortalized in the legends of the Middle East, has been reduced to about 290 individuals preserved in the Gir sanctuary in Gujarat The brow-antlered deer of central Burma and Javanese rhinoceroses are now limited to no more than 50 to 60 individuals There are now in all about 100 individuals of Africa's finest antelope, the giant sable The wild ox of Eusope, the forerunner of European domestic cattle, was wiped out in about 1627. The dodo, the most famous of all extinct birds, died out in 1861. In all cases man seems to have been the agent of destruction

Australia provides a good illustration showing how faunal invasions and competition might have acted in the past Before the immigration of man, Australia was inhabited by two lower groups of mammals, the pouched marsupials and the egg-laying monotremes Only the rodents immigrated there as waifs on floating logs, and the bats were already there as they could fly across ocean barriers The mice and the dingo dog were probably introduced by the early human immigrants Among the animals introduced by the white man, were fox, brown rat, rabbit and sheep Many domesticated dogs and cats that were imported took to the forest life and for all practical pusposes became wild beasts They practically wiped out the rat-kangaroo and the rabbit-bandicoot Rabbits multiplied so much that even an endless campaign of shooting, poisoning, fumigating, fence-building, and biological warfare has not brought them under control

CHAPTER TWENTYONE

THE QUATERNARY PERIOD — V

EVOLUTION OF MAN—I

The Precursors

Monkeys, Apes, Australopithecines and Pithecanthropi

The history of mammals dates back to the Permian Period when maternal instincts were first developed in the small reptiles known as theriodonts. They were so named because they were the first vertebrates with teeth differentiated into molars, canines and incisors, each with its characteristic form and function. These creatures escaped extermination from the ruling dinosaurs in the Jurassic by taking refuge in the trees. During the late Cretaceous many of them came down to the ground to occupy the space vacated by other reptiles. A small number, however, continued to live in the trees and became the ancestors of the primates. They were still tiny creatures, about the size of the tree-shrew, and lived on insects and tender shoots. But living in trees called for a variety of movements and consequently their forelimbs were modified for grasping. The mammals of the early Tertiary had five fingers and five toes. As time went on, these became specialized in various ways and reduced in number in some cases. In tree-dwellers, the fingers and toes became prehensile for the purpose of grasping branches of trees. While in some mammals the upper parts of limbs are attached to the sides by the skin, in the case of primates the limbs are articulated to the body at the shoulders and hips which ensures greater freedom of movement. Tree-dwelling animals developed this feature and also the capacity of assuming an erect posture by standing on hind legs.

judging distance and seeing objects as solid (stereoscopically) instead of just flat". In response to this ocular advancement there was a corresponding development of the brain and of the nervous system related to vision together with modifications of the different parts of the body A first step in this direction was taken by a few insectivores like the tree-shrews which took to living in the trees Next came the lemurs and tarsiers with large eyes Fossil remains of a group of small animals allied to living tree-dwellers like tree-shrews, lemurs and tarsiers have been found in early Tertiary rocks

With the progressive development of an erect stature, the backbone began to function as a column upon the top of which was placed the head in perfect balance The earliest known primate is *Plesiolestes problematicus* from the Paleocene rocks of Wyoming in the USA In the Eocene are found the true lemurs and tarsiers In the New World, lemurs became extinct by the Oligocene, but continued in the Old World and today they are common in Malagasy The tarsiers are more advanced, and appeared later than the lemurs The next higher group is that of monkeys In zoological classification, the sub-order Anthropoidea includes monkeys, apes and man Fig 77 gives a chart showing the evolution of man and apes

The earliest true monkey, *Parapithecus*, is known from the Oligocene of Egypt The New World monkeys are more primitive and represent a blind alley of evolution The Oligocene of Egypt has also yielded fossils of the first known ape, the small *Propliopithecus* Its appearance at this time indicates, according to Swinnerton, that the apes directly evolved from the tarsiers bypassing the monkeys During the early Miocene the evolution of the apes was continued in the region of Lake Victoria in central Africa where a gibbon like ape, called *Limnopithecus*, and *Proconsul*, which is a common ancestor of gorilla chimpanzee and man or a direct forerunner of man, have been found

From the late Miocene until the Ice Age, forests dwindled with the advent of cold followed by dry climate The true apes, unable to give up the habit of living in trees retreated southwards with the forests, and kept to the more uniform living conditions of the tropical forests where there was less incentive to evolution *Proconsul*, with legs and arms of the same length shows that it took to living in open country while its heel and leg bones give indications that it must have at least assumed a semi-erect posture. *Dryopithecus* from the Miocene of India and Europe had features that could be ancestral to modern apes but from its size and weight it is doubtful if it could spend much time on trees Many species of *Dryopithecus* have been discovered from the Siwalik hills *Ramapithecus brevirostris* bridges the gap between the anthropoid apes of this period and australopithecines *Sivapithecus* is another fossil ape Several members of Dryopithecines have been discovered from the Siwaliks Recently an almost complete lower jaw of a Dryopithecine has been found near Haritalyangar in Bilaspur district, Himachal

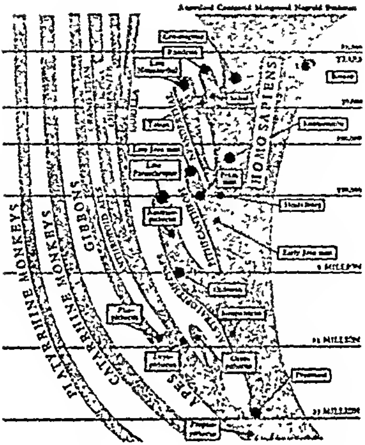


FIG 77 CHART SHOWING THE EVOLUTION OF MAN AND APES (Courtesy UNESCO)

Pradesh, and is currently under study by the Chopra-Simon team at Panjab University, Chandigarh.

LOWER PALAEOLITHIC MEN AND THEIR CULTURES

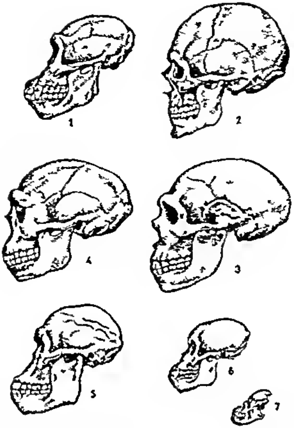


Fig 78 Skulls of 1 Modern chimpanzee 2, Modern man 3, Neanderthal man 4 Peking man 5 *Australopithecus* (hominid) 6, *Proconsul africanus* 7 *Adapis parisiensis* an ancient lemur (Courtesy UNESCO)

brows, flat nose and a protruding muzzle (Fig 78) These hominids lived in bands in the cave fissures Fig 79 shows a chimpanzee and a reconstruction of an *Australopithecus*

Another important member of the Australopithecinae is the Oldoway man, *Zinjanthropus boisei* discovered in 1960 from Oldoway Gorge, Tanganyika, from the beginning of the middle Pleistocene The remains of *Zinjanthropus* in the form of jaws and skull bones are associated with pebble tools and bones of various animals like rats pigs, sheep cattle and giraffe, who served as food for Oldoway man *Zinjanthropus* had man like teeth but had much larger jaws than those of man. He had a long face, with the cheek bones like those of *Homo* large frontal sinuses but no heavy brow ridge The brain capacity was larger than that of *Australopithecus* His importance lies in being the first tool maker The pebble tools are associated with artificially rounded stone balls

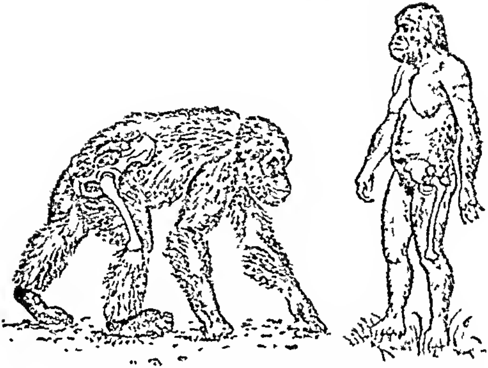


FIG. 79 CHIMPANZEE AND RECONSTRUCTION OF AN *Australopithecus* SHOWING MODIFICATION OF PELVIC GIRDLE
(After Charles Singer et al. *History of Technology*, Vol. I Oxford, 1954)

FIG. 80. *Palaeanthropus erectus* (After H. R. Knipe)

Pithecanthropi

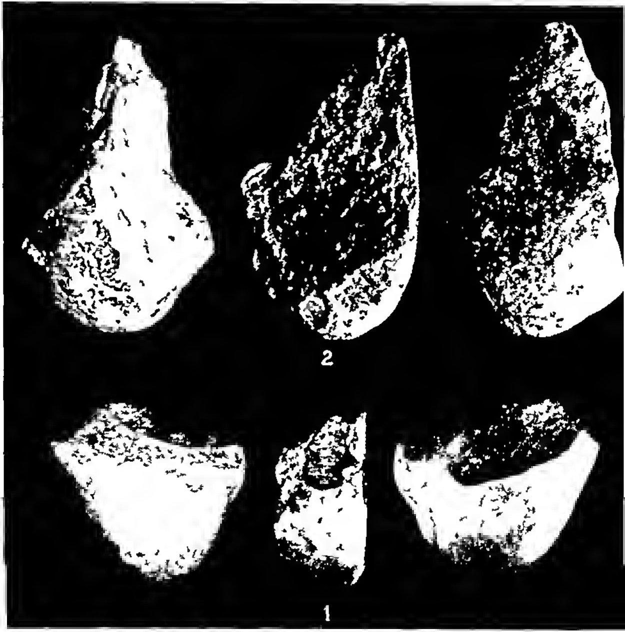
Another centre of human evolution existed in the Far East where the pithecanthropi developed The oldest of Java fossils are from Djetis deposits dating from mid-Pleistocene The most famous of pithecanthropi is *Pithecanthropus erectus* (Fig 80), discovered at Trinil in Java by Dubois in 1890 The name was chosen after Haeckel's hypothetical linking of man with an anthropoid ancestor *Pithecus* meaning 'ape' and *anthropus* meaning 'man', therefore, *Pithecanthropus erectus* means 'erect ape-man' The find consisted of a brain-case, a thigh bone and three teeth The brain capacity is 750–900 cc which is between the average of modern apes and man The deposit is diagnosed as of lower Pleistocene Pl 86 shows a reconstruction of *Pithecanthropus erectus*

Pithecanthropus pekinensis was discovered in a curious way The Chinese had been, since several centuries, using ground fossil mammalian teeth for medicinal preparations Finding of some fossil human-like teeth in a Chinese drug shop led to the discovery of the fossil remains of *Pithecanthropus pekinensis* in a Pleistocene deposit in the Choukoutien caves near Peking The remains were found associated with charcoal, very primitive stone implements and burnt bones of elephants, giant rodents, etc The fossil was originally named *Sinanthropus pekinensis* meaning China man from Peking Subsequently, it was found that there was no difference between *Sinanthropus* and *Pithecanthropus* Both are now assigned to *Homo erectus* and the Peking man is a subspecies of *Homo erectus*, and, therefore, called *Homo erectus pekinensis* The Peking man was rather short statured The brain capacity was about 795–1225 cc which falls within the modern human range He made rough chopping tools and scrapers from pebbles, which represent the Choukoutien culture He had discovered the use of fire and used it for warming caves The control of fire is the first great human achievement for which credit goes to Peking man (Fig 81) In the cave, associated with very crudely fashioned flakes of quartzite and other stones, bones of extinct animals were found that had been subjected to the action of fire At first, man kept alive the fire produced by lightning or natural agency Later, he discovered the trick of kindling fire while hitting flint or quartz pieces against one another He might also have learnt to produce fire by the friction of two pieces of wood Fire was perhaps the first step towards man's emancipation from the bondage of his environment With fire he could endure Arctic cold, penetrate into deep forests explore caves for shelter, scare away dangerous animals and cook food Peking men were hunters, used flint implements and fire, and had a lithic culture

Some unusually large teeth twice the size of corresponding teeth in gorillas and six times as large as those in modern man, were found in a Chinese druggist's shop in Hong Kong They were thought to belong to some extinct giant apes or men and,

By permission J. H. McGregor. Courtesy of American Museum of Natural History, New York

RECONSTRUCTION OF PITHECANTHROPUS ERECTUS: FRONT VIEW



Courtesy B B Lal and A cl aeolog al S rvey of Ind

STONE IMPLEMENTS FROM INDIA

1, Unifacial chopper type Palaeoliths from Guler in Kangra valley 2 Pebble handaxe-type Palaeoliths from Kangra

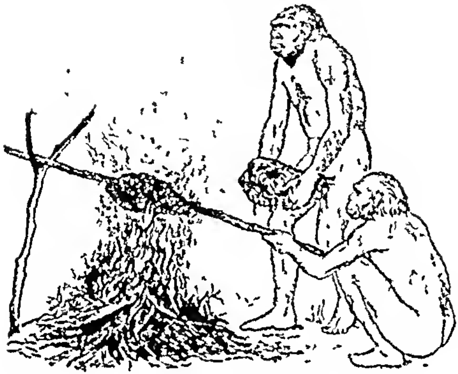


FIG. 81. *Pithecanthropus pekinensis*: PEKING MAN (After R. Carrington, *A Guide to Earth History*, London, 19[illegible])

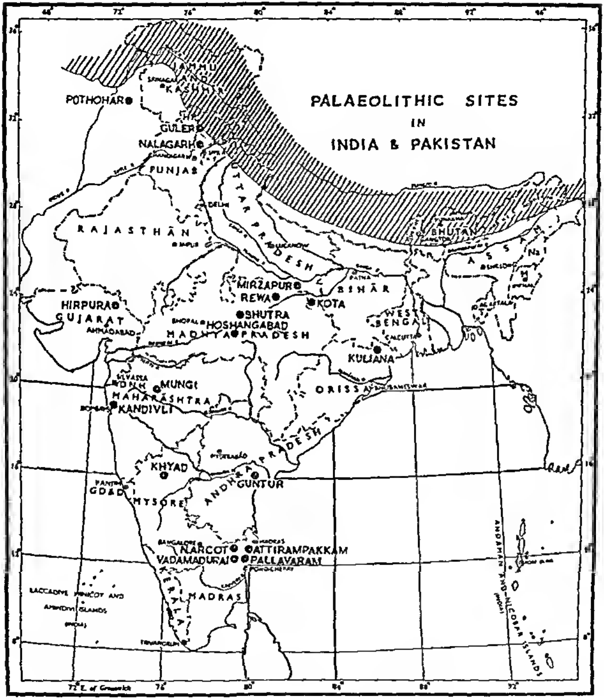


Fig 82. Map of India and Pakistan showing the distribution of Palaeolithic sites

In the valleys of the Chambal and its tributaries in Rajasthan and Malwa, and in the Yamuna valley in the Banda district of Uttar Pradesh also Palaeolithic assemblages have been recorded.

Early to late Soan implements have also been found in the Singrauli Basin, Mirzapur district in Uttar Pradesh and in the Mayurbhanj district of Orissa.

In the valleys of the Sabarmati and Mahe in Gujarat, mixed industries of pebble tools, bifaces and flakes have been recorded.

The river terrace system of the Irrawaddy river in Burma is the same as that found in the adjoining Shan plateau, and strongly resembles the terrace system of the Potwar and adjoining regions of India and West Pakistan. The number of terraces is the same, erosional and depositional features are similar, as also the succession of pre-historic cultures in which early Palaeolithic core-pebble tools are gradually mixed and partly replaced by flake tools of a more advanced type. The first evidence of the human industry, known as the early Anyathian, is found in Terrace 2, deposited in times of heavy rainfall. In Terrace 4, a more advanced type of Palaeolithic implements is found. Terrace 5 contains deposits similar to those of recent rivers.

Thus, during the Soan time, the hunters of the Irrawaddy valley in north Burma were making rough choppers, chopping-tools, hand-axes and large scrapers, characteristic of the Anyathian culture, and at Choukoutien in north China, the immediate ancestors of *Pithecanthropus pekinensis* must have been using rough quartzite and some fashioned limestone as tools, as such implements were found with their fossil remains. It is, therefore, apparent that by the second interglacial, the Choukoutien culture was established in north China, the Anyathian in Burma, the Soan in West Pakistan and India, and the Patjitanian in Java. The last has been identified in the valley of the Kali Baksoka stream and some places in southern Java from large clumsy tools, mainly choppers made from water-worn pebbles and massive flakes.

In the region comprising the Indo-Pakistan sub-continent, Burma, Java and China, the culture seemed to have belonged to a different and generally less progressive type, which in the words of Jacquetta Hawkes 'had no comparable creation to rival the hand-axe'. This is known as the chopper-chopping-tool complex and shows a high proportion of tools made of rough flakes.

Chopping tools and choppers made out of large, round, and flat pebbles formed the most characteristic implements of the Soans who also fashioned flake tools. The pebble and flake tools became smaller and better shaped as time went on. The latest Soans, who lived during the Riss glaciation and the succeeding interglacial, developed a culture apparently like that of the European Levalloisians, who were known for their "tortoise-core" technique.

In the south and central India, during the pluvial period which corresponded in part with the second and later interglacials of the Himalayan region, pear-shaped or oval core-tools, flaked on both faces to give a continuous cutting edge, the so-called hand-axes, were prevalent. There was, however, a regular interaction between this industry, known as the Madras Industry or Madras-Acheul, and the Soan Industry. The former dominated the south and south-east and the latter the north.

According to present findings, the northernmost limit of pithecanthropi was Germany. *Homo heidelbergensis*, represented by a lower jaw, was discovered from Mauer sands near Heidelberg in the lower Pleistocene deposits. The jaw is massive, without a projecting chin, but the teeth are very human. The jaw was found associated with the remains of Pleistocene elephants, rhinoceroses, horses, etc. estimated to be about 450,000 years old. Heidelberg man was the contemporary of Java and Peking men. He has some affinities with Neanderthal man who seems to be his successor.

CHAPTER TWENTYTWO

THE QUATERNARY PERIOD—VI

EVOLUTION OF MAN—2

Arrival of *Homo sapiens*

as against 220 or less among ancestral apes Thus lengthening of the embryonic period has carried with it delay in the hardening of the skull, and so increased growth of the brain, enabling it to register more and more delicately facts of vision and hearing especially Not only has the pre-natal period been lengthened, but the human body has become increasingly dependent for a longer time, thus the scope of maternal devotion has increased '

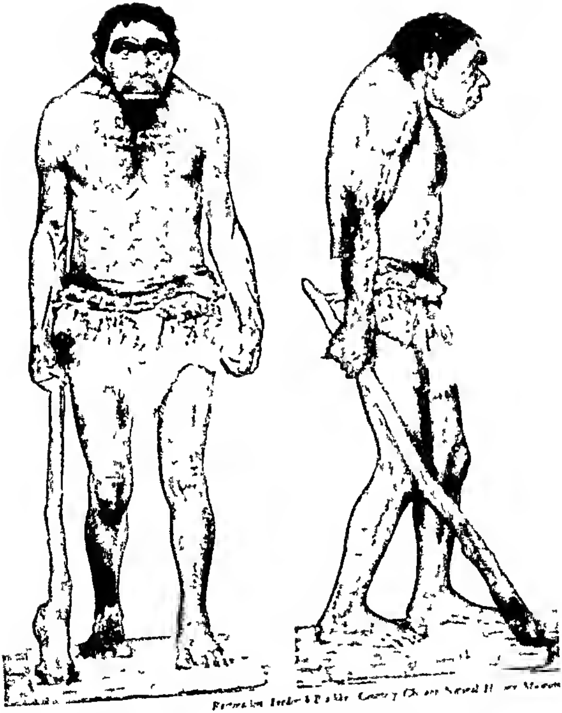
The helplessness of the infant made it difficult for the mother to run with the group and thus probably led to division of labour between males, and females who kept the home This also strengthened the bond between mother and child and it is thus that education developed Communication between mother and child gradually took the form of modern types of speech through refinement of the ears

MIDDLE AND UPPER PALAEOLITHIC MEN AND THEIR CULTURES

The Neanderthal Man

The last remnant of palaeoanthropi, the Neanderthal man, *Homo neanderthalensis*, was first discovered from the late Pleistocene deposits in the Neandertal valley near Dusseldorf in Germany Subsequently, numerous skeletons of this species were found from various places in Europe, north Africa, Iran and Iraq (Fig 83) From these discoveries, it appears that Neanderthal man lived in Europe, Africa and western Asia some 72 000 years ago He was short, had a low receding forehead, protuberant brows long arms, bent thighs walked with a stoop, and had a matted coat of hair (Pl 88) His brain-case was large, but the brain was poorly developed. He hunted a variety of animals including cave-bears and hairy mammoths and cooked their meat on fire Pl 89 shows a group of Neanderthal men hunting a mammoth Their weapons were boulders and spears of wood tipped with blades of flint Hunting in a pack requires organization, planning and strategy In this respect they showed a great advance over pithecanthropi who probably relied on individual skill in hunting The Neanderthal man used stone-tipped arrows and buried his dead with great ceremony In the cave of La-Chapelle-aux-Saints, the corpse was accompanied by Mousterian implements and joints of meat His social and cultural achievements comprised middle Palaeolithic civilization

Gradually, however, he increased his stock of tools by adding knives, spearheads, awls, scrapers, and the like, all made from chips struck from the original core of flint used in making the hand axes He also used spear and sling as his weapons He also began to work in bone and horn To meet the growing demand for flint, he sunk shafts to get at sub-surface deposits when those on the surface were exhausted. Such advances



[illegible] Courtesy Chicago Natural History Museum

NEANDERTHAL MAN: FRONT AND SIDE VIEWS

NEANDERTHAL MEN HUNTING A WOOLLY MAMMOTH

A sabre toothed tiger two woolly rhinoceroses a b son and a herd of Megaceros (giant elk) are seen in the background

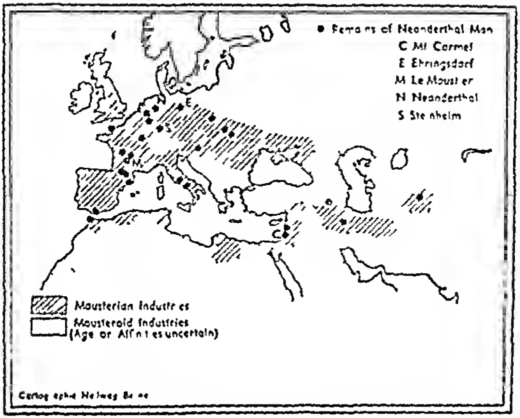


FIG. 83 MAP SHOWING THE DISTRIBUTION OF NEANDERTHAL MAN AND THE MOUSTERIAN AND RELATED CULTURES (Based on a map in Charles Singer et al. *History of Technology*, Vol. I, 1954. The Clarendon Press, Oxford)

was taken by the Cro-Magnon man (Pl 90), the modern species, *Homo sapiens* More than 100 specimens of Cro-Magnon man have been collected in western and central Europe His brain capacity was equal to that of the present day man The development of large cerebral hemispheres with corresponding enlargement of the forehead, prominent chin and small canines are the main distinguishing features of *Homo sapiens*, which are also noticeable in the Cro-Magnon man The archaeologists refer the products of these men to upper Palaeolithic industries In France, the cultural periods belonging to this closing phase of the last Ice Age are referred to as Aurignacian, Solutrean, and Magdalenian "The physical difference between men of the Aurignacian and Magdalenian cultures on the one hand and the present day men on the other is negligible while the cultural difference is immeasurable", says Leakey Thus man's physical progress has practically come to an end, while progress in culture has taken its place

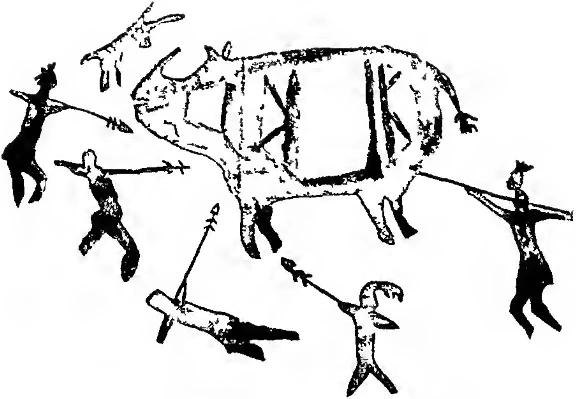
The Aurignacians. The Aurignacians, named after cave deposits of Aurignac on the upper Garonne in France, built up a varied cultural life Their culture comprised flint implements of advanced type They had the spear-thrower and the bow, perhaps the earliest devices developed by man to augment the energy of the arms There were a few core tools longer, narrower and thinner, and flint implements were delicately worked Favourable conditions prevailed in central France The limestone plateaus were steppes, on which browsed animals Fishes were abundant in the rivers, and mountain caves offered convenient habitations

A similar culture, known from the making of fine tools from relatively small flakes of flint is called Capsian, after the ancient Capsa in Tunisia This culture entered Spain by the Gibraltar land bridge and crossed into Italy and southern France by the land-bridge that existed between Tunisia and Sicily The early Capsian may be older than the Aurignacian culture, which lasted from 11,500 to 10,000 B C, during which the Aurignacians not only carved figures and engraved objects, but also decorated the walls of caves in which they lived with paintings of woolly mammoth, woolly rhinoceros cave-bear, bison, reindeer lion horse, fish, cattle and stag Possibly, they were painted for magical purposes to ensure good hunting Carvings of many of these animals and of human figures were made on horn, tusk and bone In one cave, clay models of bison have been found Evidently, the Cro-Magnon people were artistic. Later, there was much greater improvement in workmanship By patiently applying pressure near the edge of a flint (pressure-flaking), small, thin, lace-shaped flakes, often of exquisite delicacy of workmanship, were produced

The Solutreans. The closing phase of the Aurignacian culture saw the steppe

Courtesy American Museum of Natural History, New York

RECONSTRUCTION OF CRO-MAGNON MAN



PAINTING FROM A CAVE IN THE MIRZAPUR DISTRICT SHOWING THE HUNT OF A RHINOCEROS

upper Palaeolithic, needle had been invented, and sewing of clothes from the skins of hunted animals was done by women

Remains of dwellings of upper Palaeolithic men have been discovered from Soviet Union and Czechoslovakia A group of six elongated rectangular underground houses, 3×12 m. have been discovered at Timonorka near Briansk in Russia. Floor was 3 m. deep, walls were lined with timber, and roofs were made of logs covered with earth. Stone lamps, burning animal fat, were used for light, warmth, and possibly also for cooking and heating

An encampment of upper Palaeolithic men has been discovered from Ostrava–Petrovice in Czechoslovakia, consisting of three oval huts, 6–8 m. long, with a pair of hearths set in the middle, in which coal was burnt for fire The roofing consisted of skins of wild animals Piles of bones and tusks of mammoths indicate that the inhabitants were mammoth hunters They also hunted reindeer, ibex, bison, pig, horse, and wild cattle

The invention of the chisel, the gouge and awl led to working on bones, tusks and antlers Bone spear points and needles were invented Wood was also utilized for making spears.

Upper Palaeolithic Cultures of India

Implements made of agate, jasper, ebert, and chalcedony, mostly blades, burins, cores and scrapers have been discovered by Sankalia in the valley of Pravara, a tributary of Godavari Rough tools and flakes of Clactonian-type have been recorded from Khandivli near Bombay by Todd. These tools were possibly used for cutting up carcasses and scraping skins

Domestication of Dog

Dog was domesticated by Palaeolithic man about 20,000 years ago Wolves and jackals often hang around human dwellings as scavengers, feeding upon bones and crumbs of flesh The earliest dogs were probably like Indian pariah dogs, and Javanese chow. These types followed the Palaeolithic hunters round the world, breeding with other local species like wolf and jackal, which though distinguished as Linnaean species, are still interfertile That the dog entered into the ecological system of man very early is borne out by the fact that man and dog are universally distributed together, even in remote regions like Australia, Greenland and Alaska.

The progenitors of the American-Indians came from Asia by way of the Bering Strait into North America, perhaps between 20,000 and 15,000 years ago They brought

CHAPTER TWENTYTHREE

THE QUATERNARY PERIOD—VII

THE NEOLITHIC CULTURE

Invention of Polished Stone Implements, Discovery of Agriculture and Domestication of Animals

DURING THE Neolithic or the Polished Stone Age, man acquired the skill of grinding and polishing stone implements like celt, axe or adze, and invented the sickle for harvesting crops *He began to control his food supply by cultivating plants and domesticating animals* Bernal regards the invention of the technique of agriculture, ranking with the utilization of fire and of power, as one of the three most momentous inventions in human history

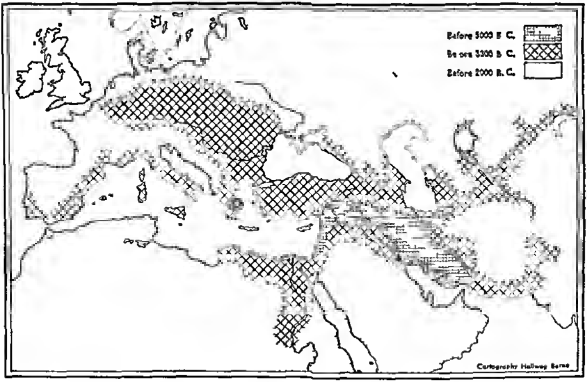


FIG 84 THE DIFFUSION OF FARMING INTO ASIA AND EUROPE (Based on a map in Sonia Cole The Neolithic Revolution. By permission of the Trustees of the British Museum—Natural History Courtesy UNESCO)

Like all great transformations, it was not a single act but a process including numerous observations and inventions, all subservient to the essential achievement—the cultivation of seed-giving grasses. Apart from the discovery of agriculture and animal husbandry, other achievements of the Neolithic revolution were wood-working, and manufacture of pottery and textiles. Thus, when we speak of Neolithic revolution, what is implied is not a catastrophe but a major change in the techniques of food production which gave man control over his environment and saved him from the precarious existence of a mere hunter and gatherer of wild berries and roots. For the first time, he lived in settled villages, and apart from security from hunger, he also had leisure to think and contemplate.

The epicentre of the Neolithic revolution was western Asia, the region embracing Palestine, Anatolia, Mesopotamia, the Caspian Basin and the adjoining Iranian plateau (Fig. 84). It is in this region that wild ancestors of two major cereals, wheat and barley, and of domesticated animals like goat, sheep, pig and cattle (*Bos primigenius*), are found.

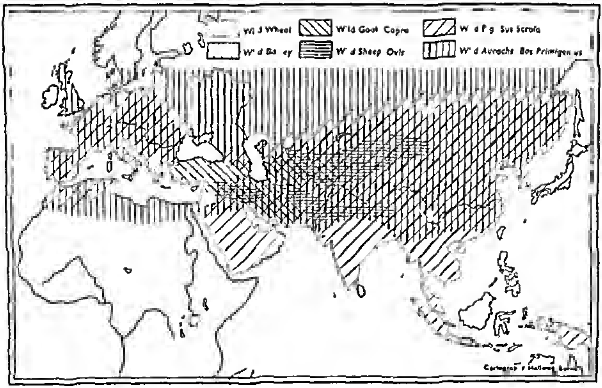


FIG. 85. THE DISTRIBUTION OF THE WILD ANCESTORS OF DOMESTIC PLANTS AND ANIMALS IN THE OLD WORLD (Based on a map in Sonia Cole, The Neolithic Revolution. By permission of the Trustees of the British Museum—Natural History. Courtesy UNESCO)

Thus apart from fertile soil, all the requirements of mixed farming which include agriculture and stock raising were present in this region (Fig 85)

The oldest Neolithic settlement sites known are Jericho in Jordan (7000 B C), Jarmo in Mesopotamia (6700 B C) and Belt Cave below the Caspian (6500 B C) in northern Iran Between them, they, more or less, embrace the region which saw the rise of Neolithic culture (Fig 86) According to Braidwood, Jarmo and other ecologically similar localities witnessed the first attempts at agriculture In the region about Jarmo, the present day botanical evidence strongly substantiates the idea, that here are found wild wheat, wild barley, lentil, pea, flax, fig and almond—all of which are potentially domesticable in their present forms, or have potential factors for hybridization All are found in a definitely wild state, that is, in uncultivable situations, so that they must be considered as indigenous and not as later introductions From this region, Neolithic culture diffused in a series of waves to Aegean and Levant, Egypt South Russia, Balkans and Danube valley, Italy, France, Spain, the British Isles and India Thus, the Neolithic culture which began about 7000 B C in western Asia

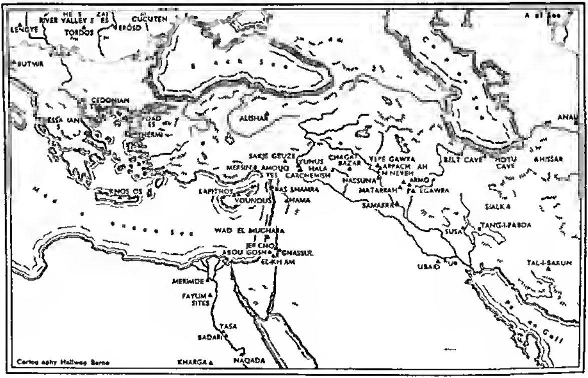


FIG 86 NEOLITHIC SETTLEMENT SITES IN SOUTH WEST ASIA AND EAST EUROPE (After J Braidwood, Oriental Institute University of Chicago Courtesy UNESCO)

reached Spain about 4500 B C and the British Isles about 3000 B C By the time the New Stone Age was established in Britain, Egypt and western Asia had already entered the Bronze Age (Fig 87) Large areas in a number of regions remained backward. When Captain Cook discovered Australia, the local population was practising Palaeolithic economy, and the Maoris in New Zealand were using polished stone tools Though the use of metals began in India about 2500 B C, still there are Neolithic survivals in the form of querns, stone mortars and pestles in large number of village homes Same is true of many other parts of the world

Polished stone axe or celt, with its edge carefully ground, was an important tool which enabled the Neolithic men to obtain a foothold in the forests In the forest clearings, these farmers started the cultivation of crops Very often, fire was used for burning forests, and grains of cereals were dibbled with the aid of pointed sticks, as is still done

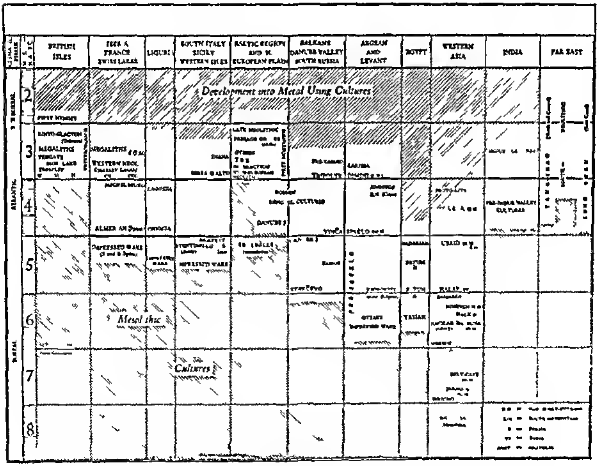


Fig 87 Neolithic cultures of the Old World (des. A. T Ruby Courtesy UNESCO)

by some farmers in the hill areas of Assam Later on, stone hoes with wooden handles were invented Sowing of crops was largely the work of women who are credited with the discovery of agriculture It was only after the domestication of cattle and invention of the plough, which came much later, that woman was liberated from the toil of cultivation In most States in India, even now while ploughing is done by man, it is the woman who follows behind, and drops the seed in the furrows

CULTIVATION OF PLANTS

It is the cereals—wheat, barley, rice, millets and maize, which have contributed most to the building up of the Neolithic culture They yield nutritious food and the grains can be easily stored for a number of years All the cereals have arisen from wild grasses, and wild ancestors of a number of them are known One of the major differences between the cultivated forms and the wild ancestors is that in the latter, seed is shed as soon as it is ripe, while in the former, seeds remain enclosed in their husks and can only be separated by threshing The cultivated forms possibly arose from a lethal mutation as a result of which non-shattering varieties developed which could be harvested, threshed and winnowed A fascinating history of cultivated plants has been built up by the discovery of carbonized seeds and impressions on potsherds from archaeological sites Study of pollen has provided evidence of farming which is inferred from the occurrence of cereal pollen or the pollen of weeds associated with cultivation Sculptures and paintings depicting agricultural operations also provide evidence of past agriculture Other evidences are storage pits, pots, sickles, hoe-blades and saddle-querns

The Old World Plants

Wheat. Vavilov recognized 14 species of *Triticum*, which fall into three groups with 7, 14 and 21 chromosomes respectively Among these the most ancient are 7-chromosome wheats comprising *T aegilopoides*, the wild einkorn, and *T monococcum*, the einkorn Carbonized seeds of both these have been found at Jarmo Both these species have fragile stems, loose spikelets, and a single seed in each spikelet Both of them easily hybridize Wild einkorn is found in Armenia and Georgia in the Soviet Union, and in western Iran There are no records of this wheat in India, Africa or China Einkorn is still cultivated in hilly regions of Europe and the Middle East Its importance lies in the fact that it is the ancestor of all other cultivated wheats excepting emmer

There are seven species of 14-chromosome wheats They originated by hybridization and chromosome doubling of 7-chromosome einkorn with a 7-chromosome wild grass which is still unidentified Only wild species with 14-chromosomes is the wild emmer,

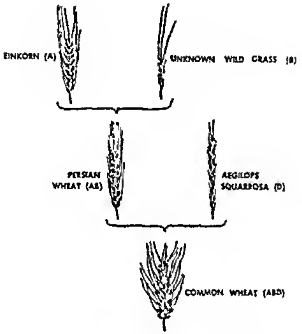


Fig 88 Ancestry of common wheat (After P C. Mangelsdorf)

T dicoccoides, which is found in Armenia northern Palestine, Syria, Turkey, and western Iran The wheat found at Jarmo is of an irregular type with coarse and loose ears comparable to *T dicoccoides* From its original home, emmer diffused into Egypt and Europe The earliest record of emmer is 4000 B C

The 14-chromosome wheats have tough stems and seeds which thresh free from their glumes and consist of 4 species *durum* (macaroni), *persicum* (Persian), *turgidum* (rivet) and *polonicum* (Polish)

The 21-chromosome wheats comprise five species and are widely cultivated Of these, *T aestivum* (common), *T sphaerococcum* (shot) and *T compactum* (club) are true bread wheats which comprise 90% of wheat grown today Grains of *T sphaerococcum*, the common wheat of northern and central India, found from Mohenjo-Daro are dated about 2500 B C, and this wheat seems to have been grown widely in the Indus valley The evolution of wheat is illustrated in Fig 88

Barley. There are two species of cultivated barley, the two-rowed (*Hordeum distichum*), and the six-rowed (*H hexastichum*) The wild ancestor of two-rowed barley is found in Palestine, Arabia, Asia Minor, Transcaucasia, Persia, and Afghanistan, and of the six-rowed barley in eastern Tibet The earliest find of barley is from Jarmo

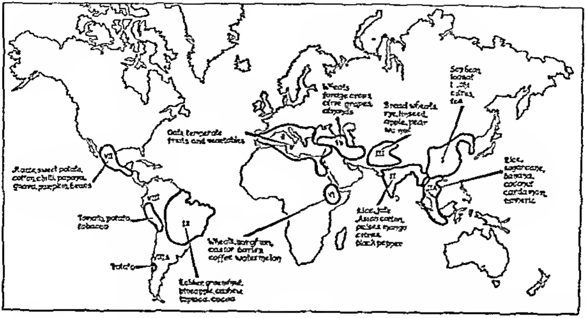


FIG 89 CENTRES OF DIVERSITY AND ORIGIN OF CULTIVATED PLANTS (General assignment after Vavilov, 1935 and Darlington & Janaki Ammal, 1945)

Millets. Millets are annual warm-weather cultivated grasses, and thrive in regions of low rainfall Common millet (*Panicum miliaceum*) was cultivated in India and central Asia in early times Sorghum was cultivated in Assyria about 700 B C Other millets like *ragi* (*Eleusine coracana*), *cheena* (*Panicum miliaceum*) and *kutki* (*Panicum miliare*) have been cultivated since proto-historic times in India Italian millet (*Setaria italica*) is a descendant of *S viridis*, that grows wild in western Asia

The region extending from Punjab to Caucasus, apart from bread wheats and barley, is also the home of Asiatic cottons, small-seeded flax, onion, plum, apricot, peach, almond, cherry, apple, pear, grape, walnut, strawberry, etc (Fig 89) Carrot has been detected from Neolithic remains from Switzerland and Germany, and possibly resulted from the hybridization of two wild species *Daucus carota* and *D maxima* Apples eaten in Danube area were the wild crabs It is stated that the Danubians introduced the cherry-plum in central Europe where the cultivated plum developed by crossing with wild sloe Pistachio nuts, peas and lentils have been recovered from Jarmo Olive was cultivated *in south-eastern Spain in the Neolithic*

Flax. The Neolithic Egyptians grew flax (*Linum usitatissimum*) and it has also been discovered at Alishar in central Anatolia at a level dating 3000 B C It is also known from Navdatoli-Maheshwar (1700 B C) in India *Linum bienne* was cultivated by the Danubians, and the inhabitants of Swiss-lake dwellings

Rice. The genus *Oryza* to which rice belongs has 24 species, of which 22 are wild and two, *O sativa* and *O glaberrima* are cultivated. All the rice varieties of Asia, Europe, and America belong to *O sativa*, and of West Africa to *O glaberrima* India has 5 wild species, of which *O sativa* var *fatua* is a common weed in Madhya Pradesh, Kerala and Punjab *O perennis*, found wild in Orissa, has a short rhizome, branched floating stem and perennial habit In wild rices grains shatter easily and are difficult to harvest It is considered that *O sativa* evolved from the wild rices by mutation and selection It is thought that rice cultivation originated in India, Burma or Indo-China India has 4000 varieties of rice The earliest record of rice is from Lothal in Gujarat, about 2000 B C *O glaberrima* had probably an independent origin in West Africa

Malayan migrants introduced rice cultivation in Indonesia in proto-historic times Rice was introduced in the Philippines by immigrants from South China in the first millennium B C It is they who developed the vast terrace system in the mountains of Philippines On account of its heavy yields, rice could support far denser population than any other cereal, and consequently population in rice lands increased at an explosive rate

The New World Plants

Maize The American civilization, before the advent of the white man, was based on the cultivation of maize Even now it is the most important crop plant in America and is mostly used to feed livestock and poultry It was introduced in the Old World after the discovery of America by Columbus in 1492 Formerly, the eastern slopes of Andes, where the greatest diversity of maize varieties is found, were regarded as the centre of its origin However, the oldest specimen of maize cob has been discovered from Bat Cave in New Mexico State of USA which has been dated to 3600 B C by Carbon-14 Wild maize occurred in this region since the last Interglacial about 60,000 years ago According to Mangelsdorf, the cobs discovered at various levels reveal a distinct evolutionary sequence The oldest cob was hardly the size of a thumb, and there is progressive increase in size as we reach the upper strata Mangelsdorf regards a wild pod popcorn as the ancestor of maize With the passage of time, there was an increase in the size of the cobs as well as of plants (Fig 90 and 91)

Other crop plants. A cave near Ocampo in Mexico has yielded varieties of cultivated gourds, lima beans and squashes dated to about 6500 B C The Neolithic folk inhabiting the Chicama and Viru valleys in Peru about the middle of the third millennium B C raised squashes, gourds, beans and chillies, but maize was unknown amongst them They also grew cotton and used it for weaving fabrics, nets and bags

Apart from maize, the New World contributed potato, sweet potato, cassava,

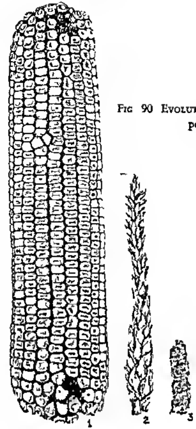


FIG 90 EVOLUTION OF THE MAIZE COB 1, Modern dent corn; 2, the ancestral form of pod-popcorn; 3, an actual prehistoric cob from La Perra Cave (After P. C Mangelsdorf)

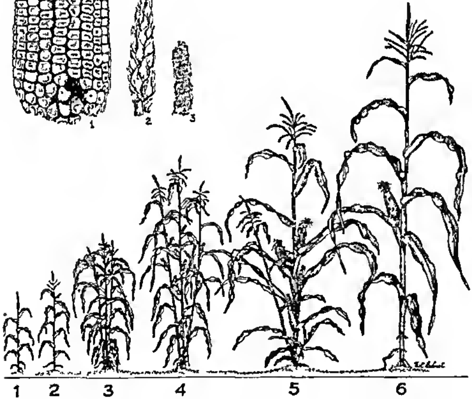


FIG 91. EVOLUTION OF THE MAIZE PLANT. 1, Wild pod-popcorn, 2 & 3, improved by cultivation, 4, after loss of pod-corn gene; 5, increased distance of male flowers, 6, modern dent corn from the US corn belt (After P. C. Mangelsdorf)

tapioca, beans, tomato, chillies, pumpkin, papaya, pineapple, guava, custard apple, groundnut and cashewnut Its other contributions were tobacco, American cotton, and rubber

DOMESTICATION OF ANIMALS

During Neolithic times, along with cultivation of cereals, the domestication of animals was also carried on This became possible, because habits and habitats of animals and plants, and their reproduction and growth came under keen observation Domestic animals like sheep, goats, and cattle are movable sources of food, and their dung is used as fertilizer Goats and cattle also supply milk The hair of sheep and goats can be woven into cloth or beaten into felt The use of animals to carry loads or draw ploughs and vehicles is a later adaptation

Change in climate and the advent of aridity are regarded as important factors favouring domestication of wild animals With the decline of food and water supplies, the wild animals herded hungrily round the scattered oases around which human settlements had already been established The close contact of wild animals with man paved the way for their domestication

The time sequence in which wild animals were domesticated is as follows Firstly, goat and sheep, secondly, cattle and pigs, and lastly, draught and transport animals like the horse, the ass and the llama This is borne out by the excavations carried out in Belt Cave where remains of domesticated sheep and goats are found in the earliest pre-pottery horizon dated to first half of sixth millennium, while remains of pigs and cattle are found in the second half of the same millennium

Sheep and goats. All varieties of domestic sheep have descended from three species of *Ovis* found wild in the mountainous regions of Asia and Europe The earliest to be domesticated in south-west Asia was *Ovis vignei*, the urial, found wild from Tibet to Elburz mountains Descendants of *Ovis musimon*, the mouflon, are found in Sicily, Corsica, Sardinia, Cyprus, Anatolia and northern Iran *Ovis ammon*, the argali, is found in mountainous regions of Soviet Central Asia Goat has descended from the bezoar goat of Afghanistan and Turkistan

Cattle. There are two varieties of cattle, the humped, found in India and Pakistan, and the humpless found in Europe and other areas The bones of humped zebu (*Bos indicus*), along with hand-made pottery and flint blades have been discovered from Rana Ghundai in Baluchistan about 3000 B C The zebu is also depicted on pottery discovered from this site No doubt, the process of domestication must have started a few centuries

earlier. The humpless varieties are descendants of the aurochs, *Bos primigenius*, depicted in Lascaux cave paintings Braidwood mentions that aurochs continued to exist in Poland in the eighteenth century The earliest finds of domesticated cattle, according to Heichelheim, came from Mesolithic northern Europe and from Egypt, and later from the Mediterranean, the Near East and northern India

Pigs. All domestic varieties, except the Chinese variety, are descendants of wild pig, *Sus scrofa*, still found in India, central Asia as far as Siberia, north Africa and Europe. Pigs were also domesticated in Sweden and Italy at the beginning of the Neolithic According to some, pig breeding originated in India and east Turkistan and spread through the Mediterranean region to Europe The Chinese variety is said to be descendant of *Sus vittatus*, found wild in south-east Asia

Horses and camels. Remains of horses and camels have been discovered from Rana Ghundai along with those of zebu Bones of horses have been recovered from Neolithic sites in Europe and Asia

Llama and alpaca. These were the only transport animals of the New World Llama is said to be the descendant of wild guanaco of the highlands of South America.

HOUSING

A distinctive feature of Neolithic culture was the development of houses built of locally available materials Walls made of pise or sundried bricks were popular in south-west Asia, Africa and China The oldest known Neolithic houses are of Jericho and Jarmo in which both stone and pise were used The walls were lined with lime plaster, and floors were plastered and burnished with smooth stones The wooden door frames were possibly provided with skin curtains Stone and wood were used by the European farmers along the Mediterranean In the interior of Germany and Denmark, long houses built of timber, were common In most of the favoured areas, human habitations surrounded by cultivated fields and pastures appeared As Jacquetta Hawkes remarks, ' By 4000 B C in the cradle land of farming, by 2000 B C in the regions of its primary diffusion, large tracts of land in Asia, Africa and Europe had become man-made landscapes".

POTTERY, BASKETRY AND CLOTHES

Development of agriculture and production of food grains in sizable quantities lead to the problem of storage Pots were required not only for storage of foodgrains, but

also for cooking Though Jericho was occupied in the eighth millennium, the first pots are dated about the middle of the sixth millennium First pots were hand-made from clay, and the use of wheel in pottery came much later Baking of pots is of significance for the beginnings of science As Gordon Childe observes, "It is the earliest conscious utilization by man of a chemical change" The use of pottery extended the range of cooking operations and improved the diet of man

Basketry was first developed in Iraq Iran, Palestine and Egypt Coiled basketry was popular in Egypt Weaving was made possible by abundant supplies of flax and wool Flax was the material used for textiles in early Neolithic times in Egypt, Asia, and Europe According to Jacquetta Hawkes, the Danubians, the windmill people of England and the first Scandinavian settlers had no textile garments, but relied entirely on skins and furs Spinning and weaving, and making of pots is again credited to women

Invention of weaving had deeper implication As Bernal observes, "Weaving is clearly a further adaptation of basket-making and both of them involve regularities, first of all actually practised and then thought about, which are at the basis of geometry and arithmetic The forms of patterns produced in weaving and the number of threads involved in producing them are essentially of a geometrical nature, leading to a deeper understanding of the relations between form and number"

Saddle-querns were used for grinding grain Possibly parched grains were used, and the grinding operation may not have been so arduous Techniques of baking and brewing also developed

Whyte thus sums up the achievements of the Neolithic culture "The whole social life of man was revolutionized by conscious planting of edible grasses and berries, and animal breeding increasing food sources such as meat, milk, eggs and honey, the range of clothing (wool, silk, fur, leather), and of tools which in addition to flint, could be made of horn, bone or feathers These commodities, like number of heads of cattle, created new economic capital"

NEOLITHIC CULTURE OF INDIA

While Punjab, Sind, and parts of Rajasthan and Gujarat were in an advanced state of civilization about 2500 B C, the rest of India was still in the early Neolithic stage Neolithic sites in India fall in four groups—northern in Kashmir, southern comprising Andhra and Karnatak, eastern embracing Assam, Bihar and Orissa, and the fourth group comprising central and western India with sites in Chambal valley (Nagda) and Narmada valley (Maheshwar)

The most interesting discovery of Neolithic culture dating to about 2000 B C has been made from Burzahom in Kashmir valley The Kashmiris of Burzahom lived in circular pits which were provided with landing steps The presence of post holes indicates that some type of roofing was provided Tools consisted of polished stone axes of various kinds (Pl 92) Apart from stone tools, bone tools comprising harpoons, needles, and chisels were also used A crop cutting instrument, the like of which has been known from China, indicates that cultivation was practised here No direct evidence of cereals grown by the Neolithic Kashmiris has come forth, but seeds of weeds, like *Lithospermum arvense*, species of *Trifolium*, *Lotus corniculatus* and other species of *Lotus*, *Medicago denticulata* and *M falcata*, and species of *Ipomoea* and *Euphorbia* have been recovered (Pl 93) Most of these are weeds occurring in cultivated fields, dry pastures and waste lands, and are usually associated with cultivation of wheat and barley Recent "pollen analytical" investigations carried out in the Haigam lake, not far away from this site, reveal that the origin of cultivation in the valley started within the blue pine forests which were cleared by the Neolithic man The climate was much cooler than at present Subsequent clearances were confined to the broad-leaved forests of oaks and alders which had replaced the conifers The cultivation was of a shifting type

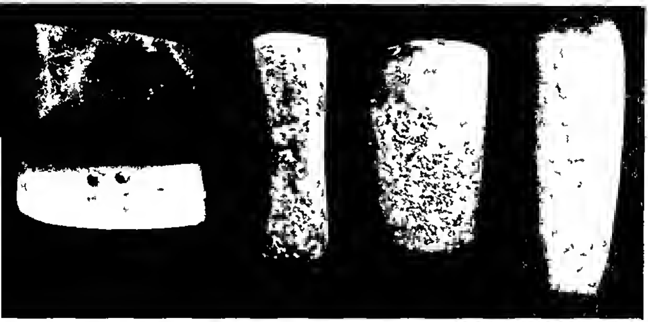
Southern Neolithic culture was characterized by burnished grey pottery, polished stone axes and urn-burials The excavations at Utnur in Andhra Pradesh have shown that the so-called ash-mounds were in all likelihood cattle pens This site has been dated 2000 B C The people kept humped zebu cattle Excavations at Nevasa by Sankalia have shown that Nevasians lived in shallow pits which were roofed with reeds resting on wooden posts

Raichur and Bellary districts are looked upon as the original home of the Neolithic cultures in south-east India The region is studded with bare granite hills with huge boulders scattered on the plains About 2000 B C, pastoral-cum-agricultural people lived here and manufactured hand-made pottery on turn table From Takkalkota, a site in this region, carbonized seeds of *kulthi*, *Dolichos biflorus*, have been discovered (Pl 93) The *kulthi* is cultivated today in the Karnatic and Deccan on poor soils as a fodder crop

From Hallur, another Neolithic site in the Karnatak, carbonized millet and fruits of teak and jujube (*ber*) have been recovered The millet has been identified as ragi, *Eleusine coracana* It is believed to be the cultivated form of *E indica*, a wild species found in India

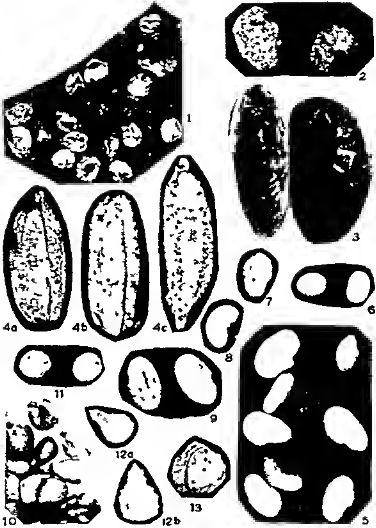
Teak (*Tectona grandis*) does not occur today in this region but is present in the adjacent area It usually occurs in fairly moist and warm climate in regions of high rainfall, up to 500 cm, along the west coast It appears that the granite hills during Neolithic times were wooded with teak and the climate was not so dry as today.

From the north-east part of India in Orissa, rice has been discovered from Baidipur, a recently excavated Neolithic site (Pl 93)



Courtesy Archaeological Survey of India

NEOLITHIC POLISHED STONE IMPLEMENTS FROM BURZAHOM, KASHMIR VALLEY, 2000 B C



After Vishnu Mittre

SEEDS FROM THE NEOLITHIC OF INDIA

1, *Eleusine coracana* (carbonized) from Hallur in Karnatak 2 & 3 *Dolichos biflorus* (carbonized) from Takkalkota, Karnatak 3, enlarged to show hilum scar 4 (a b & c), rice husks from Baidipur, Orissa, 5 to 13 seeds from Burzahom Kashmir 5, *Medicago denticulata*, 6 *Lotus corniculatus*, 7 & 8 *Trifolium* spp 9, *Medicago falcata* 10 *Ipomoea* sp , 11 & 13, unidentified 12 (a & b), *Lithospermum arvense*

Thus, during the Neolithic, millet and rice were cultivated in India and indirect evidence of wheat and barley from Kashmir is also there The occurrence of seeds of several weeds and fodder crops in the settlement sites, probably also suggests their use as food by the Neolithic folk

When one compares Burzahom and other Neolithic sites in India with Chalcolithic sites of Sind, Punjab, Rajasthan and Gujarat, one cannot help remarking that these were backwaters which continued to preserve techniques which had long been superseded in the area which came under the influence of Harappan culture much earlier This also explains the anomalous position of Neolithic cultures in India which, unlike those of other countries, are younger or contemporary with the Bronze Age cultures

CHAPTER TWENTYFOUR

THE QUATERNARY PERIOD — VIII

THE CHALCOLITHIC CULTURE

THE BRONZE AGE

THE TERM CHALCOLITHIC is applied to communities using stone implements along with those of copper or bronze. In more advanced communities, the proportion of copper and bronze implements is higher than that of stone implements. The Chalcolithic revolution, like the Neolithic, was the climax of a long process. It was the ultimate result of what Gordon Childe calls "The Second Revolution between 6000 and 3000 B.C. which transformed tiny villages of self-sufficing farmers into populous cities, nourished by secondary industries and foreign trade, and regularly organized as States. The scene of this drama lies in the belt of countries between the Nile and the Ganges. During this period, man has learnt to harness the force of oxen and winds, he invents the plough, the wheeled cart, and the sailing boat, he discovers the chemical processes involved in smelting copper ores and the physical properties of metals, and he begins to work out an accurate solar calendar."

SUMERIAN CIVILIZATION IN MESOPOTAMIA AND EGYPT

Mesopotamia

The Chalcolithic revolution began in Mesopotamia in the fourth millennium B C. Soon after, it spread to Egypt and subsequently to the Indus valley. The valleys of Tigris and Euphrates have a fertile soil The Sumerians who settled in the deltas of these rivers had just emerged from the Neolithic stage of culture. They had splendid pottery and carried on cultivation with flint hoes. Their capital was Ur which was subsequently destroyed by flood. To the north of Sumer was Akkad which included the Neolithic sites of Jarmo and Hassuna which saw the birth of agriculture. By 3000 B.C. Sumerian civilization was fully developed, and about 2385 B C., king Sargon of Akkad conquered Sumer and unified the country.

Copper is not found in Mesopotamia and it was imported from Oman on the

Persian gulf So, it was with imported copper that the Sumerians worked and they became masters of the technique of bronze-manufacture

One of the major events of the Bronze Age was the shifting of primitive wheat varieties from the mountains to the plains Helback believes that one result of this forced movement of primitive cereals, beyond their natural habitat by the human agency, may have been the emergence of new plants With the use of bullock-drawn plough, the rich alluvial soil started yielding bumper crops of wheat Horticulture was concentrated around the urban centres The priestly hierarchy, with the concentration of surpluses in their hands, started building monumental temples, which dominated the economic life. It was also the beginning of warfare with emphasis on fortification for the urban centres There was expansion of handicraft production which led to development of trade

Mesopotamia and the adjacent lands are favourably situated among the three of the centres of origin of cultivated plants, viz Near Eastern, Mediterranean and Central Asiatic (Fig 89) The Central Asiatic is the native home of wheat, peas, beans, lentils, gram and cotton

Whyte thus sums up the contribution made by the Near Eastern and the Mediterranean centres to cultivated plants of the Old World "The world's potential sources of western orchard fruits are concentrated in the Near East, the native home of the grape, pear, cherry, pomegranate, walnut, quince, almond, apricot and fig The first orchards were undoubtedly located in the Near East In Soviet Georgia and Armenia one may still observe all phases of the evolution of fruit growing from wild groves consisting almost wholly of wild fruit trees through transitional methods to those approaching modern fruit growing, including the grafting of the better wild varieties on the less valuable wild forms Here also one may see that primitive man, while clearing away forests to make room for grain fields, has left standing the better specimens of wild apple, pear and cherry It appears that viticultural methods and all the more important grape varieties have been acquired from the Near East, where one can still find wild forms quite suitable for culture in vineyards In *Medicago*, *Pyrus* and *Amygdalus* species formation has been active and is still occurring Natural polyploidy has been discovered among wheats and numerous species of wild plants, particularly in alpine and subalpine zones From Turkey, Iran and Soviet Central Asia has come the world's wealth of melons, and the leading forage crops, lucerne, Persian clover, a number of species of *Onobrychis*, *Trigonella* and vetch"

In the cultivated plants of the Mediterranean centre, one can easily trace the important role played by man in selecting the most suitable forms, the Mediterranean forms of flax, barley, beans (*Vicia*) and chickpea are notable for their large seeds and fruits in contrast to the small-seeded forms of central Asia, their basic centre of origin,

Sowing of seed by dibbling with pointed stick gave place to hand furrowing Woolley mentions that the settlements of Al'Ubaid people in Euphrates valley are marked by the vast numbers of heavy flint hoes which litter the sites Invention of the plough, which was at first only a forked branch of a tree, brought about improvement in cultivation by field tillage Though it is not possible to credit any particular country with its invention, plough was in use in Mesopotamia before 3000 B C The Sumerian plough had a tube attachment through which seed could be dropped This is the earliest seed drill known Copper was as yet expensive, and hence, denticulated flint sickle blades were in common use up to the middle of the third millennium B C

Wheeled cart. Apart from the plough, wheeled cart was another proud possession of the Harappan civilization Children's toys include some wheeled carts, which indicate that they were in use in ordinary life Bernal states that bullock cart combined two critically important ideas—the use of animal power and the wheel, and the first development of the wheeled cart seems to have been by the Sumerians, possibly before they came to Mesopotamia "These inventions were to have enormous material and scientific consequences The cart and the plough between them enabled agriculture to be spread over all open plains and so far beyond the limits of the old civilizations The increased possibilities and speed of transport by cart and even more by ship, together with the need to know the sources of valuable materials, led to deliberate exploration and to the beginnings of geography"

Decline of Sumerian Civilization

Irrigated agriculture with the use of canals has its own problems What is considered a boon in early stages becomes a curse in due course The cause of decline of Sumerian civilization, according to Whyte, was salinity and water-logging After 1000 to 1500 years of irrigation, serious salinity problems developed By 1700 B C wheat had completely disappeared in the south, and barley which is more salt-resistant survived but gave lower yields *It was loss of command over environment observes* Toynbee which led to the breakdown of the civilization of Tigris Basin.

Contribution of Mesopotamia and Egypt to Human Culture

The contribution made by the civilization of Mesopotamia and Egypt to human culture is thus summed up by Woolley "Political entities of unprecedented complexity arose, occupations became specialized, involving divisions of class, trade was organized, writing was invented, monumental architecture expressed the symbolic significance of public buildings and representational art tended to replace the largely decorative art of Neolithic times".

where most of the dominant genes of these plants are concentrated "The western dispersal of vine, olive, fig, stone fruits, bread wheat, rice, ornamental and shade trees was apparently partly or wholly due to the spread of Greek and Roman civilizations To this the Arabs added the sugarcane, date palm, cotton, some types of *citrus*, lucerne and other plants The grapevine and lucerne also went eastwards into China and are clearly attributed to Chang Ch'ien about 140 B C"

Egypt

The main elements in the population of Egypt were the Libyans who came from the North, and the Semites who came from Palestine The Semites brought with them flocks of sheep and techniques of making pottery and stone vases, and elementary knowledge of metals It is they who ushered the Chalcolithic phase in the southern countries It is through them that the civilization of Mesopotamia reached Egypt In the proto-dynastic age, irrigation of fields by canals had been introduced, and towns with temples had been founded River transport by means of boats, propelled by paddles by batches of men, developed This was followed by the use of the sail, thus harnessing power of the wind in the service of man A system of writing had developed and Egyptian art had acquired its peculiar idiom

The City. The origin of the city is one of the main achievements of the Mesopotamian, Egyptian, and Harappan civilizations The rise of the city meant a new social organization, as well as origin of town planning and architecture Apart from food producers a city has preponderance of people who are not directly engaged in agriculture and are administrators, priests, traders, craftsmen and labourers Rise of a city itself means improvements in the technique of agricultural production so that non-agriculturists could also be maintained It also meant the rise of a leisured class, the priests, who could think and study It is these people who watched the stars, the moon and the sun and thus developed astrology which is the mother of the science of astronomy Already, by about 2700 B C, observations of the Egyptian priests had led to the compilation of a solar calendar The Mesopotamians developed the sexagesimal system and mathematical tables from which algebra and arithmetic arose in due course

Irrigated farming and the plough. In Chalcolithic Period, basic agricultural techniques, which had developed in hilly uplands, shifted to lower river valleys The system of nomadic shifting cultivation gave way to cereal-fallow system Irrigated farming was developed Flood waters were stored in reservoirs for irrigation purposes in the valleys of the Nile and the Euphrates, and canals were dug Hence, Chalcolithic is also called the age of irrigated farming

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Irrigated agriculture with the use of canals has its own problems What is considered a boon in early stages becomes a curse in due course The cause of decline of Sumerian civilization, according to Whyte, was salinity and water-logging. After 1000 to 1500 years of irrigation, serious salinity problems developed By 1700 B C wheat had completely disappeared in the south, and barley which is more salt-resistant survived but gave lower yields *It was loss of command over environment observes* Toynbee which led to the breakdown of the civilization of Tigris Basin.

Contribution of Mesopotamia and Egypt to Human Culture

The contribution made by the civilization of Mesopotamia and Egypt to human culture is thus summed up by Woolley · "Political entities of unprecedented complexity arose, occupations became specialized, involving divisions of class, trade was organized, writing was invented, monumental architecture expressed the symbolic significance of public buildings and representational art tended to replace the largely decorative art of Neolithic times".

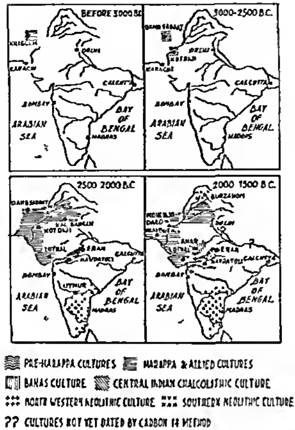


FIG 92. MAPS SHOWING THE SPREAD OF PREHISTORIC CULTURES OF INDO-PAKISTAN SUB-CONTINENT BASED ON CARBON-14 DATINGS (After B B Lal, 1964)

HARAPPAN CULTURE IN INDO-PAKISTAN SUB-CONTINENT

In India and Pakistan, the Harappan Chalcolithic culture was preceded by a pre-Harappan phase centred in Baluchistan. A pre-pottery microlithic culture has been discovered from Kili Gul Mohammed which has been dated early fourth millennium B.C. (Fig 92, Kiligulm). These people lived in houses built of mud bricks. They kept sheep and possibly cultivated crops. At Rana Ghundai, the inhabitants of the earliest phase used hand-made pottery and flint blades, tended cattle and lived in huts. Lying between the higher inland plateau of central Asia and the low flat plains of Sind, the possibilities of influences from important settlements round the south-east of the Caspian Sea, Tepe Hissar, Anau and Namasga Tepe in Russian Turkistan, can hardly be overlooked.

Pottery. Well-baked wheel turned pottery had already developed in Baluch hills about 3000 B C. Not only the technique was adopted by the Harappans, but they made

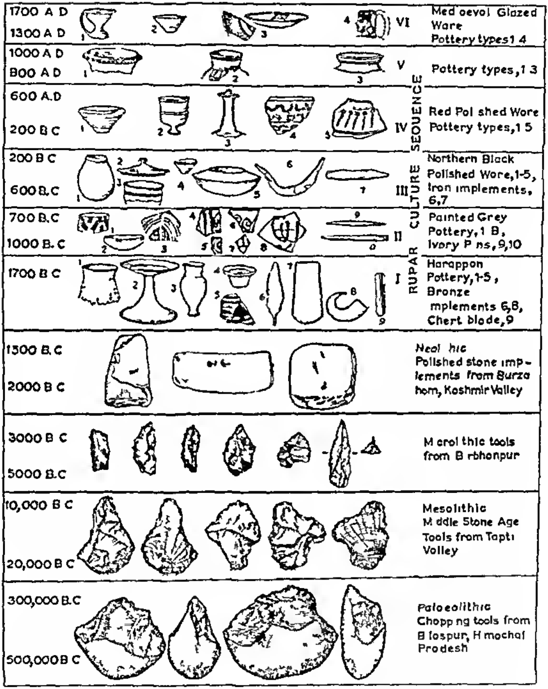


Fig. 93 Tools pottery and other implements used by man in India from Palaeolithic to historical periods Rupar culture sequence shown is from sections of Nalagarh mound Rupar Punjab (India)

many innovations in design and form Their characteristic shapes and designs can be seen in Fig 93, which includes bronze implements, chert blades and some pottery recovered from a Harappan mound at Rupar in Punjab, India, about 1700 B C.

Use of metals. The occurrence of copper ore in Baluchistan, western Himalayas and Rajasthan accounts for the rise of Chalcolithic culture in the north-west of Indian sub-continent Evidence of earliest copper smelting is found among the makers of painted pottery In early phases copper must have been worked by hammering and cutting only from natural metal or from metal smelted from ore While copper and bronze axes, daggers and spears were in use, chert blades which were provided with handles continued to be used by the Harappans on account of their cheapness and abundance (Pl 94) On account of scarcity of metal, the use of copper was restricted to weapons, tools for city craftsmen, and for ornaments for women The major technical advance of the Harappan culture, no doubt, was the use of metals, particularly that of copper and its alloy bronze

The major sites of Harappan culture are Harappa in west Punjab and Mohenjo-Daro in Sind, both in Pakistan, and two minor settlements, Kotla Nihang near Chandigarh in Punjab (India) and Rangpur in Gujarat Recently, a number of sites of Harappan culture have been discovered in north-western India, of which four are important, viz Rupar in Punjab, Kalibangan in Rajasthan, Lothal in Gujarat, and Alamgirpur in Meerut district of Uttar Pradesh Lothal was a port town with a dockyard built of kiln-burnt bricks

Cities of Harappa and Mohenjo-Daro. Harappa and Mohenjo-Daro were large cities with systematic town planning They were protected by citadels, and were planned in rectangular blocks separated by broad main streets (Pl 95) The houses were built of kiln-fired bricks, and some were two-storeyed They had three to four living rooms and were provided with a bath, a kitchen and a well Drainage system consisted of kiln-fired ring wells

The citadel at Mohenjo-Daro had massive towers of burnt brick Inside the citadel was a public bath, cloak-rooms, a square-pillared hall for public gatherings and a large granary.

The Harappans had reached a high state of culture They wore cotton garments, and used ivory combs and copper mirrors Women wore a variety of ornaments of bronze and gold They used knife blades, saws, sickles, spears, axes, arrow-heads, and daggers of bronze Bullock carts with solid wheels were used for transport They had weights of chert, steatite and chalcedony. These articles were no doubt produced by skilled craftsmen—coppersmiths, carpenters, jewellers, goldsmiths, stone-cutters and

Courtesy B B Lal and Archaeological Survey of India

CHERT BLADES FROM HARAPPA SITES

Courtesy Archaeological Survey of India

AN AERIAL VIEW OF MOHENJO DARO

potters There was a system of writing from right to left, and there must have been a class of clerks A system of trade with the adjoining countries must have developed, as most of the commodities including metals, timber and precious stones were imported There is little doubt that the idea of literate urban civilization reached the Indus valley from the earlier civilization of Mesopotamia, a country which had trade links with north India This view is, however, further strengthened by the composition of the population of Mohenjo-Daro as revealed by the examination of skulls About 50 per cent of skulls are of dolichocephalic Mediterranean-type similar to those of Al'Ubaid in Sumer, and the remaining belong to the Proto-Australoid group which represents the type comprising the main element in the aboriginal population of central and south India

Animals. The Harappan culture is represented by an art, depicting contemporary wild and domesticated animals whose actual remains in the form of bones have also been recovered from the excavations The inference from the fauna is that the climate was more humid It provided an environment for the rhinoceros tiger, water-buffalo, sambhar and elephant to thrive, none of which now exists in wild form in the region Domestic animals include humped bull (*Bos indicus*), Indian buffalo (*Bubalus bubalis*), goat (*Capra hircus*), sheep (*Ovis orientalis*), pig (*Susscrofa cristatus*), one-humped Indian camel (*Camelus dromedarius*), ass (*Equus asinus*), and at least two types of dog, one referable to the modern pariah dog, *Canis tenggeranus harappensis*, probably a derivative of some medium size wolf from the west, and the other a mastiff type The cat from Harappa (*Felis ocreata domestica*) resembles the common European domestic cat in appearance The elephant was probably domesticated by the Harappans and figures prominently in seals Apart from wheat, the Harappans ate fish, fowl, mutton, beef and pork

Crops. The Harappans cultivated bread-wheat (*Triticum aestivum*) and *T. sphaerococcum*, barley (*Hordeum vulgare* and *H hexastichum*), sesame, peas, melons, bananas, date palm, and species of *Brassica* Cotton was an important crop and the centre of origin of *Gossypium arboreum* lies in the Indus valley

Both rice and wheat have been found in several Chalcolithic sites in India Rice has been recorded from Ahar in Rajasthan and Navdatoli in Madhya Pradesh *Sorghum* has been recorded from Ahar, and pea (*Pisum arvense*) from Madhya Pradesh (Pl 96) Carbonized seeds of *Mung* (*Phaseolus aureus*), *Urd* (*Phaseolus mungo*), lentil (*Lens culinaris*) and bean (*Dolichos lablab*) have been discovered from Navdatoli Seeds and fruits of Jujube, linseed and myrobalan have also been found at this site

Increase in population. Grahame Clark estimates the upper Palaeolithic population of England and Wales as 250 human beings, 4500 in Mesolithic, 20,000 in the Neolithic, and about 40,000 in second millennium B C during the Bronze Age No estimates are available for India, but there is no doubt that in the Harappan area, the new techniques of plough cultivation and irrigated farming led to a large increase in population Kosambi estimates that most efficient hunting and food gathering can hardly support one person per square kilometre, pastoral life three, but agriculture about a hundred

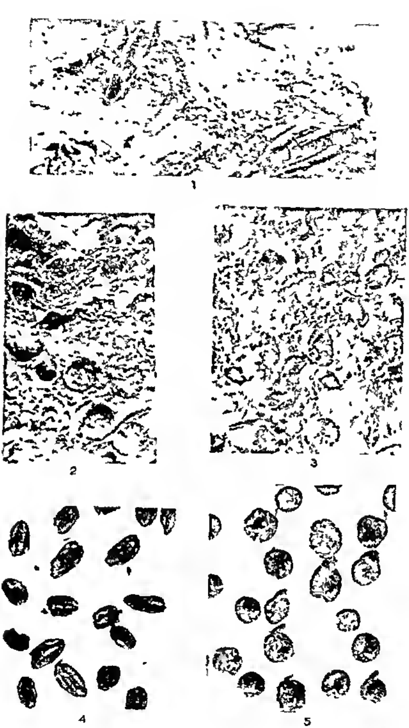
Decline of the Harappan Culture

According to Wheeler, one of the major factors of the decline and fall of the Harappan culture was widespread deforestation of the surrounding region to meet the demands of firewood for baking millions of bricks used for the building of the city of Mohenjo-Daro Large scale use of wood for baking of pottery, smelting of metals and as domestic fuel further depleted the forests Building of houses and ships also made demands on the forest reserves Clearing of land for cultivation and grazing by domestic animals were other biotic factors which led to the destruction of vegetation It is thus that man pays the price of cultural advance and civilization Eastward shift of the edge of the south-western monsoon has been suggested by Piggott as the cause of increasing aridity The final blow was in all likelihood delivered by the energetic Aryan nomads who massacred the inhabitants On the topmost level of the city remains, skeletons of men, women and children, bearing axe or sword cuts, have been discovered Though the Harappan cities were destroyed by the invaders, the achievements of Harappan culture, viz use of copper and bronze, pottery, the plough, the bullock cart, and irrigated farming were adopted by the Aryans

Chalcolithic Sites in South India

Microlithic blades of chalcedony and agate, flat axes, fish hooks, pins, and rings of copper and a distinctive black and red pottery have been discovered from Navdatoli Apart from agriculture and stock raising, fishing was also practised. The upper Godavari or Deccan Chalcolithic culture is characterized by matt-surfaced black and red pottery, polished stones, axes and pot burials

North Deccan Chalcolithic culture is represented at Nasik, Nevasa, Jorwe, etc in Maharashtra It had contact with the southern Neolithic culture of Maski Piklihal, Utnur, Nagarjunakonda of the Krishna Basin in Andhra Pradesh, since there are evidences of occasional polished stone axes and the practice of urn-burials The earliest known record of silk in Indo-Pakistan is from a burial at Nevasa

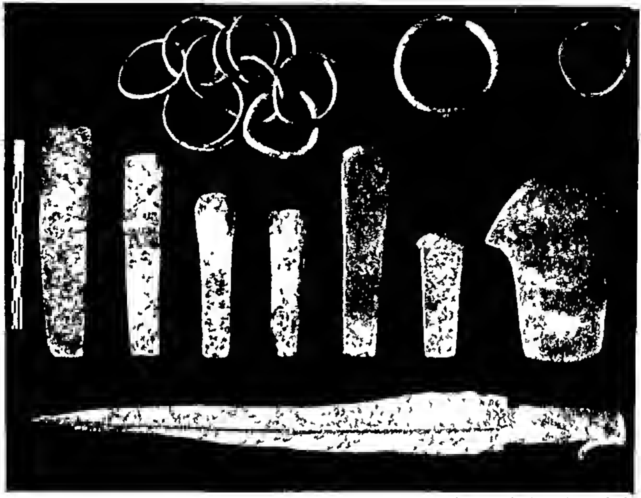


After Vishnu Mittre

SEEDS FROM CHALCOLITHIC SITES OF INDIA

1, Spikelets of rice in the matrix of a potshred from Ahar, Rajasthan, 2 & 3, Sorghum in the matrix of potshreds from Ahar, 4, carbonized rice from Madhya Pradesh, 5, carbonized seeds of Pisum arvense from Madhya Pradesh

Pl. 97



Courtesy Archaeological Survey of India

COPPER WEAPONS AND TOOLS FROM A HOARD DISCOVERED AT BAHADURABAD NEAR ROORKEE, UTTAR PRADESH (INDIA) THESE ARE ABOUT 1000 B C OLD

THE ARYANS

The Aryans originated in South Russia in the area adjoining the Caspian. About 1800–1600 B.C., they left their homeland and dispersed east and west in large hordes. It is believed that they left their ancestral land as a result of prolonged drought and famine. A large group known as Kassites penetrated into Akkad, and in due course, became rulers of Babylon in 1746 B.C. One horde occupied northern Iran, another, the Mittanis, conquered Asia Minor where they introduced horse-breeding. The third horde entered India through Afghanistan and Baluchistan and overwhelmed the Harappans (Fig. 94).

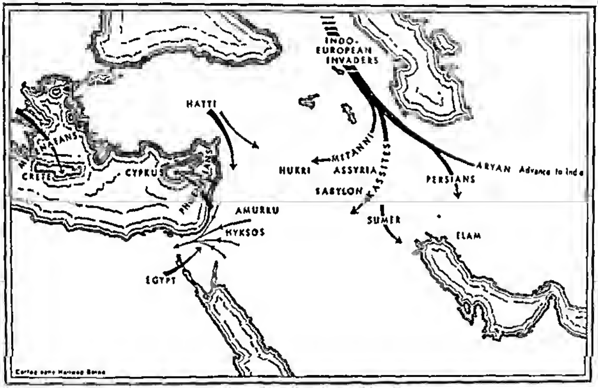


FIG. 94. MOVEMENTS OF THE MIDDLE-EASTERN PEOPLES DURING THE BRONZE AGE (Courtesy UNESCO)

The Aryans were users of bronze, and their favourite crop was barley which still plays a part in Hindu rituals, though no longer an important crop for human consumption. They were mainly pastoral and kept herds of cattle, sheep and goats. Apart from barley, beef, pork and mutton were eaten. Milk and milk products were also consumed.

The Aryans owed their success mainly to their favourite animal, horse. Yoked to a light two-wheeled chariot, it provided them with a vehicle of war, which was fast and

easily manoeuvrable Its bones have been discovered from Sialk in Iran (4000 B C), which indicates the period around which it was domesticated

Ox-drawn four-wheeled carts were used for farming and transport Fields were ploughed with heavy wooden ploughs drawn by teams of six to twentyfour bullocks

Rig Veda, which according to Max Muller was composed 1500–1400 B C, indicates that the houses of the Aryans were built of wood or reeds and cotton cloth and deer skin was used by them for clothing It was a patriarchal society divided into three classes warriors, priests and cultivators and artisans These classes crystallized into castes in due course

The Aryan conquest of the Harappan towns is indicated by references in Rig Veda to their god Indra who is described as the destroyer of fortresses From the fusion of the Harappan and Aryan cultures arose the Hindu civilization

We may also refer to copper hoards discovered from about 34 sites in Uttar Pradesh and Orissa Singhbhum in southern Bihar is regarded as the likely source of copper for these sites A famous hoard discovered from Bahadurabad near Roorkee contained a sword axes, chisels and rings of copper (Pl 97) They are ascribed to the Aryans by some, while others regard them as products of communities of hunters and fishers who practised some type of primitive agriculture There are still others who regard them as the work of refugees from Harappan towns after their destruction by the Aryans Very likely, there was indigenous local development of copper craftsmanship in the Ganga-Yamuna basin and in Orissa because of the existence of ancient copper mines in the Himalayan region north of Uttar Pradesh and in the Bihar–Orissa border areas

It took the Aryans about 500 years to conquer Afghanistan, Sind and Punjab It was about 1000 B C that they penetrated the area now known as Uttar Pradesh and Bihar Painted grey ware discovered from a number of sites is dated 1000 to 700 B C At Rupar, it overlies Harappan pottery and bronze implements Painted grey ware has also been recorded from the Purana Qila of Delhi Hastinapur in Meerut, and Ahichchhatra in Bareilly district of Uttar Pradesh and from a number of sites in Punjab It is commonly associated with the Aryans The painted-grey-ware people lived in wattle and daub houses and carried on agriculture They used only copper in the beginning and later iron as well Culturally, the copper hoards, the painted grey ware and the northern black polished ware represent the cultural sequence in post-Harappan period in the Ganges plains At Rupar, the northern black polished ware overlies the painted grey ware (Fig 93)

The northern black polished ware has a lustrous black surface, it is thin and well-fired, giving a metallic sound on being gently struck with a hammer The main sites of

this type of pottery are in northern India, but it has also been found in Maharashtra, Madhya Pradesh, Orissa and Andhra Pradesh

BRONZE AGE IN CHINA

According to Chinese traditions, China was ruled by Hsia dynasty from 2205 to 1765 B C From 1765 B C, it came under the sway of Shang dynasty who ruled the northern provinces of Hopei, Shantung Anhwei, Shansi, Shensi and Honan Excavations of Anyang graves prove that the technique of bronze casting had attained an excellence not seen elsewhere Stone carving and wood working were fully developed System of writing by pictograms had also taken shape The capital was the great city Shang It was a walled city enclosing houses constructed of wood for the upper classes, and the pit-dwellings for the lower classes

It was a powerful state, and chariots of bronze drawn by two to four horses were in use Soldiers wore bronze helmets and body armour and carried bronze-headed dagger-axes and bows

The Shang Chinese had domesticated the cattle, horse, sheep and dog Elephants and rhinoceroses were kept in parks They had also domesticated the jungle fowl, and hens were kept for egg-laying

The character of Shang civilization is essentially Chinese and some scholars believe that it developed independently According to some, knowledge of metallurgy reached China before the Shangs about 2200 B C, from West Asia

ADVANCES IN THE BRONZE AGE

The Bronze Age marks an important milestone in the progress of humanity Irrigated farming developed with the aid of canals and dams Cotton was grown in the Indus valley and flax in Egypt for the manufacture of clothes Silkworm culture and production of silk began in China in the Shang Period Achievements in agriculture and animal husbandry in the Bronze Age are summed up thus by Woolley

"In the course of the Bronze Age the agricultural economy of the ancient world assumed the form which it was to retain with very little change until mediaeval if not until modern times By 1200 B C the peoples of the different countries had selected and developed the types of cereal that best suited local conditions, and since a large proportion of the grain was grown in artificially irrigated soil they were reasonably assured of a harvest, independently of the vagaries of weather, the methods and the tools used by the farmer would be used for another millennium at least, the only change being that iron

would soon take the place of bronze. All the domestic animals of the present day were already in man's service, though the role of the horse was still but a small one, limited to the war chariot. Of tree fruits the fig, apple, pomegranate, peach and mulberry were all cultivated; dates were the most important product of southern Mesopotamia, where many varieties were grown, and were cultivated in Syria and Egypt and as far eastwards as India, where date-stone has been found in the ruins of Mohenjo-Daro. The market gardeners produced a considerable variety of vegetables. Ur-Nammu of Ur (c. 2100 B.C.) claims that as a result of building a temple to Nannar 'he saved the vegetables, in the garden plot', onions were specially favoured, as were leeks, cucumbers, and melons of many sorts."

Wheeled carts and horse chariots were used for land transport and boats with sails for water transport. Roads were built. Copper and bronze casting were prefected. Bronze tools and weapons came in use. Multistoreyed buildings of pucca bricks and stone were constructed Wooden chairs, beds and tables were invented. Glazed pottery was developed Beer and wines were manufactured. Among the intellectual achievements of the Bronze Age are development of writing, and use of weights and measures Solar calendar and astronomy are other notable achievements

EVOLUTION OF LIFE

A RESUME

LIFE BEGAN in the primitive ocean about two billion years ago Ultraviolet radiations, cosmic rays, electric discharges, and volcanic heat acting on water, carbon dioxide and nitrogen produced carbohydrates and amino acids, and the ocean water reached the consistency of a hot diluted soup From the carbohydrates and amino acids arose the DNA molecules, which in their turn produced RNA molecules Thus arose life A variety of unicellular organisms, the bacteria, protozoa, and green algae evolved

Before proceeding further with the account of the evolution of animal life, we give a summary of the evolution of plants The early period was the age of marine algae, blue-green, brown, red and green It is from the green algae that liverworts arose probably from humble ancestors like *Fritschiella indica*, a terrestrial form which grows on wet soil In the Devonian arose the first land plants, the Psilophytales The most probable known progenitors of the seed plants, the Aneurophytales represented by *Archaeopteris*, also appeared about this time From then onwards the sporophyte becomes dominant, and the gametophyte is progressively reduced Giant lycopods like *Lepidodendron* and *Sigillaria*, horsetails, Cordaitales and Pteridosperms, the seed ferns became prominent in the Carboniferous and the Permian Cycads, Ginkgoes, and other gymnosperms were the dominant plants in the Jurassic The Cretaceous was the age of Angiosperms The flower-insect partnership began in this period and evolution of butterflies, moths and honey-bees proceeded side by side with the evolution of flowering plants, the form and colour of flowers, and their scent, honey and pollen From then onwards flowering plants became prominent, and plants with yellow catkins or green cones had an humble role The herbaceous monocots are probably the latest arrivals The evolution of hoofed animals goes on side by side with the grasses The grasses provided fodder for the wild horses and cattle, and in due course, they provided cereals like wheat, rice, maize and millets, the staple food of man Fig 95 illustrates the major steps in the evolution of plants

Resuming the account of evolution of animals, we commence with coelenterates, which populated the ocean floors in the early period. Development of mouth and a special digestive cavity were their major achievements From the polyps evolved the worms, and from the worms arose the primitive chordates like lancelets From these primitive

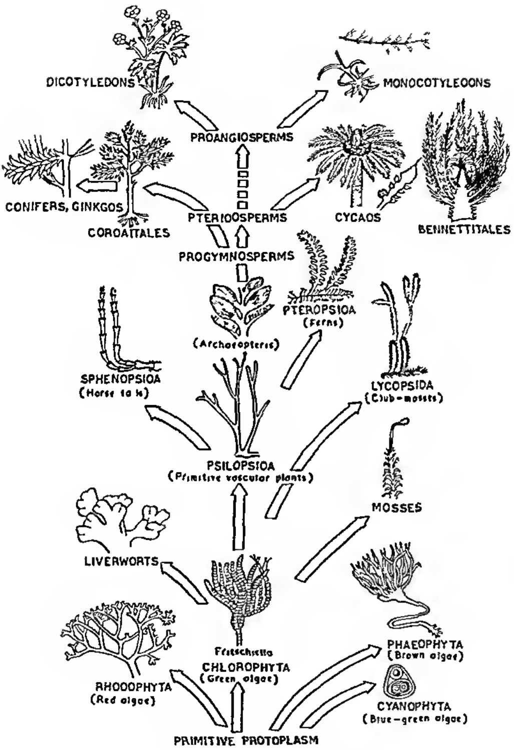


Fig 95 Major steps in the evolution of plants

chordates arose a variety of fishes. The marked uniformity in the proportions of constituent salts both in the sea water and in the blood of vertebrates indicates their marine origin. Amphibia evolved from fishes by the development of legs and invaded the land. From the Amphibia evolved the reptiles with shelled egg which conquered the land and were the dominant animals for millions of years. Then came the theriodonts who provide a link between reptiles and mammals. Then arose the primitive mammals in an humble way. They laid eggs like reptiles and had milk glands on the belly from which milk oozed which was licked by their young ones. They were warm blooded, unlike the reptiles. Then arose the marsupials, whose young ones are not placental, i.e. connected with the mother by a membrane or placenta permitting absorption of nutriment. In marsupials the teats are in a pouch in the skin of the belly, and soon after birth the young are placed there. Then evolved the mammals with placenta, the extinct lemurs from which arose the monkeys, apes, hominids and man in due course. The evolution of animal life through the ages from the primitive protoplasm to the present day man is shown in Fig. 96.

Recapitulation

Thus, we see man is part of an unbroken stream of life. Even in his own life time man rehearses the history of animal life. As Haeckel states in his biogenetic law, ontogeny repeats phylogeny, *which means that the life history of the individual gives a brief resume* of the evolutionary history of the species. Man starts as a single cell, formed by the fertilization of the ovum by the sperm, which reminds us of protozoa. Then he becomes a morula like *Pandorina*. The morula becomes a blastula or a hollow ball like *Volvox*. The ball is turned upon itself to form a gastrula or double-walled cup. Gradually, the embryo assumes chordate characters, viz. a notochord, hollow nervous system and four gill-slits. At this stage the embryos of man, rabbit, sheep, pig, chick, tortoise, salamander and fish are so alike that it is easy to mistake one for the other (Fig. 97). The heart in all these embryos is a single series of pumping chambers as in fish. The whole arrangement of blood vessels and nerves and their relation to the clefts is piscine. These facts led to the general law that animals resembled each other more and more the farther back we pursued them in development.

In some cases in human beings the gill-slits fail to close so that openings remain on the sides of the neck. The first gill-slit persists and forms the eustachian tube connecting the inner ear with the throat. The ear is in fact developed from the first gill-slit. The tail, well developed in the embryo, is free, movable and has muscles for wagging it. A clothing of long dark hair called 'lanugo' covers the entire body of the embryo except the palms and soles up to the sixth month. Babies born prematurely in the sixth month

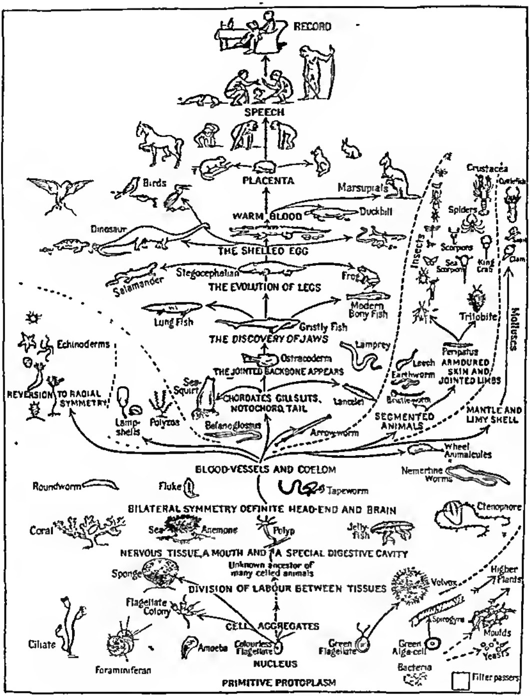


FIG. 96 EVOLUTION OF ANIMALS (After Wells, Huxley and Wells *The Science of Life*, 1931. Cassell & Co Ltd, London)

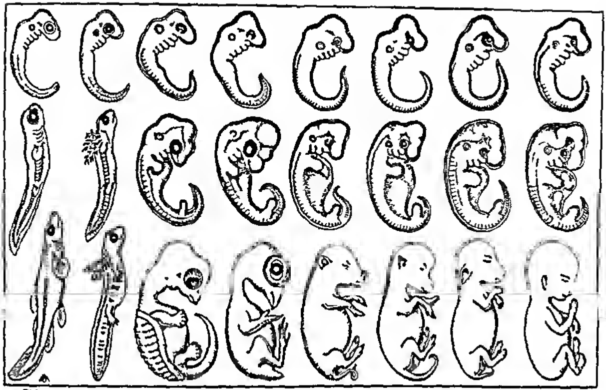


FIG 97 STAGES IN THE DEVELOPMENT OF EMBRYOS FROM FISH TO MAN Note the presence of tail and gill slits in the human embryo (After B C Gruenberg *The Story of Evolution* 1929)

are hairy and are referred to as *bijoos* The hairy covering disappears before birth In some cases it persists, and the Russian 'dog-man' Adrian Jefuchjew is a classical example of this type (Fig 98) In fact, there are a large number of men in the Aryan race who are hirsute. Hairiness increases with age in most men

Vestigial Structures in Man

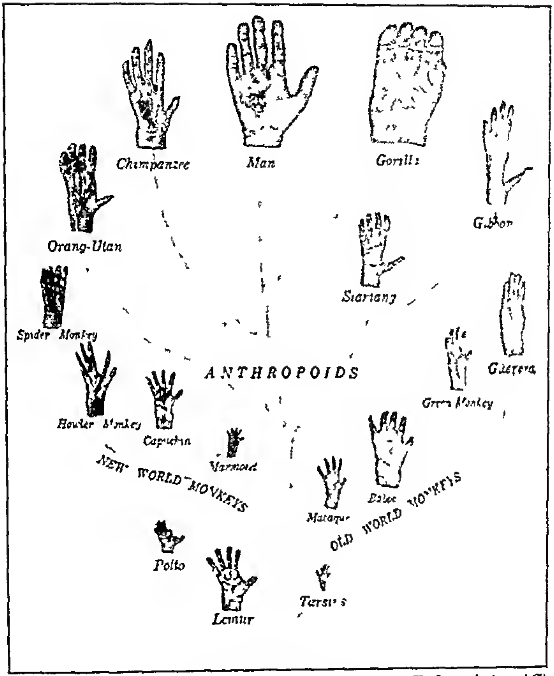
We have traced the evolution of animal life from amoeba to man The human body bears traces of the past, and is a museum of relics According to Wiedersheim there are 180 vestigial structures in man that have lost their functions as a result of evolutionary changes The vermiform appendix is a digestive organ in herbivorous mammals, while in man it is useless, and even a source of trouble In kangaroo it is very large, and in the human foetus it is longer than in the adult. The 'Darwinian point' to the human ear is the reduced ear tip. Ear muscles in man are functionless, though in some cases, men can move their ears like animals The 'plica semilunaris', a crescentic fold of membrane in the inner corner of the eye is a remnant of the third eyelid. The direction of hair on the human body is very ape-like. The hair upon the arms run from shoulder to elbow,

FIG 98 THE RUSSIAN 'DOG MAN' ADRIAN JEFTICHJEW, SHOWING ATAVISTIC DEVELOPMENT OF HAIR (After Wiedersheim)

and from wrist to elbow. Orangs when they want to protect themselves from rain sit with hands elasped above the head with elbows pointing downwards, and this helps in draining off rain water. Human child in its early stages is capable of supporting its weight from a branch for over two minutes. In such a posture the attitude of the lower limbs and feet is very simian or ape-like The tail has disappeared in adult man, but in some abnormal cases it persists

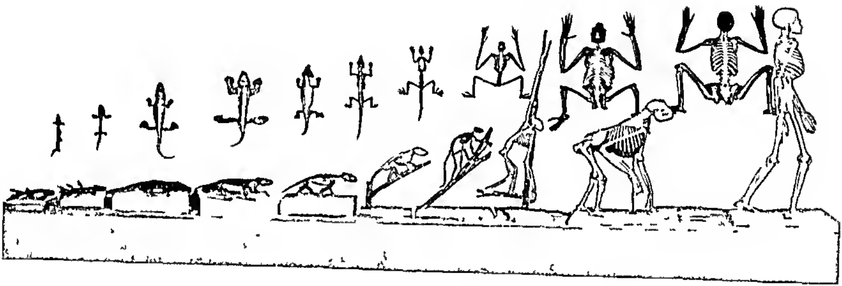
Evolution of Human Organs

Most of the organs of man, both internal and external, show a high degree of perfection and specialization, developed during the course of evolution. Take for example, the human hand The hand in *Tarsius* is prehensile and mobile, but ill-developed. In anthropoid apes, orangutan, chimpanzee, gibbon, and gorilla it shows considerable development. The apes having lost their tails like man, swing themselves along by their arms when moving in the branches of trees. This is known as brachiation, and this development leads to the broadening and flattening of the chest, and greater development of hands, and their sensitivity to the shapes of objects. It is, however, the hand of man which shows greatest perfection (Pl. 98). The thumb is opposable, i e. it can be placed opposite each finger. A variety of movements is possible. This led to the



After W. K. Gregory from B. C. Gruenberg, The Story of Evolution, 1929

EVOLUTION OF THE HAND



Courtesy American Museum of Natural History, New York

THE SKELETON FROM FISH TO MAN

manufacture of tools and implements which are really utilized as extension of the hand, and its powers of grasping and manipulation

As compared with the foot of the anthropoid apes the human foot shows specialization for running The major changes are the development of the shock-absorbing arch, the axis of the foot running through digit one, which becomes the great toe, and the others diminish in size and length

The evolution of the skeleton from fish to man and the upright posture in man is illustrated in Pl 99 The earliest vertebrates lived exclusively in water and swam by undulating the body The fins were projections of the skin and body-wall that served chiefly as rudders and balancers Gradually, in the swamp-living, air-breathing fishes, the pectoral and pelvic fins were transformed first into paddles and then into limbs as the animals crawled out of the swamps After many ages the animals invaded the uplands learning to crawl like turtles and lizards Next they learned to raise the belly off the ground and run about Then they climbed up into the trees and became expert in running and leaping about among the branches At first these tree dwelling animals ran about mostly on top of the branches Then some of their descendants adopted the 'suspension grasp' as they began to swing from branch to branch The gibbon, is rather over-specialized in this direction Avoiding extreme over-specialization for brachiation (swinging with arms), the ancestors of man came down from the trees, running perhaps occasionally on all fours, but more and more often erect as do the gibbons when on the ground From his pre-human anthropoid ancestors, which were related to the chimpanzee and the gorilla, man has inherited his ability to hold the body erect or balanced on the hind legs The forelimbs being relieved from their former function as locomotor organs were set free to serve the enlarging brain in defending the body and providing for its needs

Another advance seen in man is the basin-shaped pelvis which aids in supporting the viscera while the body is in erect position In apes the pelvis has a flattened form In the human embryo, the pelvis is flattened, and gradually assumes the basin form as the time of birth approaches

The lower jaw in man and other mammals consists of but one bone on each side, while in fishes, amphibia and reptiles it consists of a number of bones In the earliest Theromorpha the lower jaw resembles that of reptiles In later forms, however, the two hinge bones of the jaws grow smaller and are to be found in the region of the ear In mammals and man these two bones, called hammer and anvil, along with a third bone, form the middle ear, and transmit the vibrations of the ear drum to cochlea, the organ of hearing (Fig 99)

In the evolution of brain we notice the concentration of the nervous matter from the

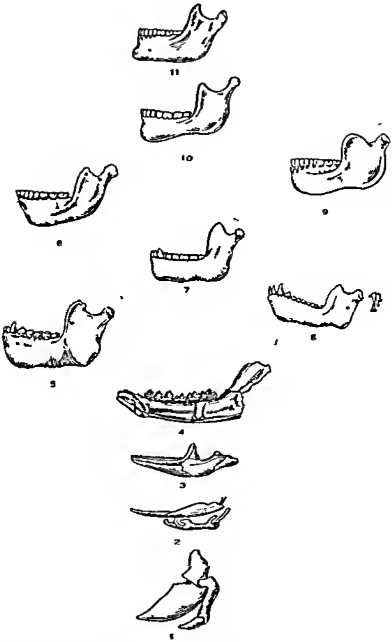


FIG. 99. EVOLUTION OF THE LOWER JAW FROM FISH TO MAN 1, Dog fish, 2, frog, 3, lizard, 4, triconodon mammal; 5, fossil chimpanzee, 6, chimpanzee, 7, *Pithecanthropus erectus*, 8, Neanderthal man, 9, Heidelberg man, 10, Cro-magnon man; 11, Modern man

scattered nerve cells of coelenterates to the highly complex human brain, which is one of nature's marvels (Fig 100) The principal functions of the nervous system, viz. reception, conduction, correlation and elaboration of impulses are general properties of the protoplasm In protozoa there are no indications of nervous differentiation In coelenterates the first nerve cells appear which exclusively serve the function of conduction of stimuli and thus bring this function to a higher perfection The first appearance of brain is in earthworm with its cerebral ganglia, and thus the head as distinguished from the rest of the body appears for the first time among animals The next step is in primitive chordates like *Amphioxus* A hollow nerve cord lies immediately above the notochord, and is swollen at its anterior portion From fishes and Amphibia onwards to reptiles, we notice greater elaboration with differentiation into cerebral hemispheres, cerebellum, and optic lobes In mammals, cerebrum greatly exceeds the cerebellum in size In apes cerebrum greatly increases in size and entirely covers the cerebellum, and is convoluted. The human brain shows further advances, but it differs not in kind but only in degree from the brain of apes As Lull remarks, man's brain as compared with ape's brain is physically merely a relatively larger and more refined example of the same fundamental type The two hollow cerebral hemispheres are so large that they have become deeply folded and convoluted The final characteristic which lifts man above other animals including apes is articulate speech, whereby he communicates his thoughts to others In the evolution of man, it is the development of the brain which is of prime importance As Jacquetta Hawkes sums up, "Throughout this vast stretch of time the increase in the size and complexity of the neo-pallium or New Brain makes the central theme, in the fossil skulls which are our principal record of the human epic we see the forehead and vault rising their capacity swelling Here, housed within the curved bone plates of the skull, is the most subtle and complex instrument in the world, which, at the command of the whole man has created the rich and varied cultures, the superb individual works of art, the inspiring if never final systems of thought, that make the history of mankind "

Evolution of Man

In man we see the culmination of animal evolution As we have already stated in an earlier chapter, about a million years ago the Australopithecines had adopted an upright bipedal posture They were competing with carnivorous animals and according to de Beer, they "owed their survival solely to three developments the perfecting of the brain as an organ to control behaviour, the social organization of their populations and the perfecting of the hand, now freed from locomotory functions, as an efficient manipulative organ". To a great extent these advances are due to paedomorphosis, viz the slowing down of embryonic and post-embryonic development, e.g teething, sexual

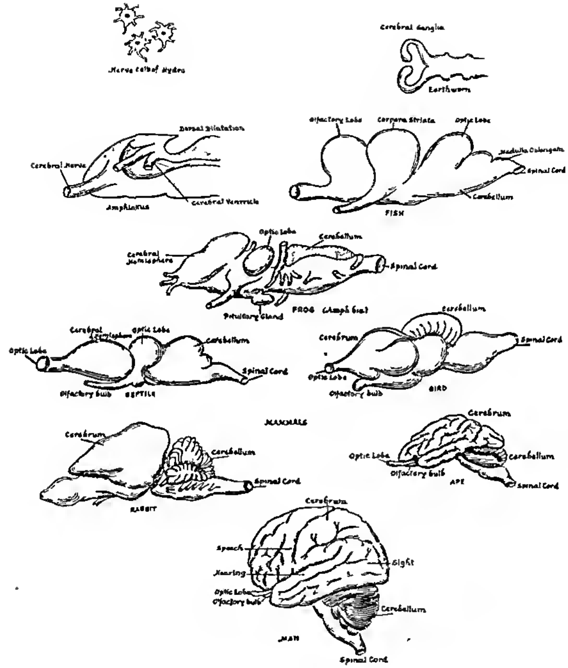


FIG 100 THE EVOLUTION OF BRAIN FROM THE GANGLIA OF EARTHWORM TO THE HUMAN BRAIN Note the increase in the size of the cerebrum and its complexity in man

maturity, suturing of the bones and loss of the heavy bony brow ridges of Pithecanthropi Retardation in development led to an extended period of infancy in which parental care was necessary Thus resulted in the establishment of the family as a stable biological unit, essential for survival It also provided a nucleus for social organization and ultimately lead to humanization Man acquired the capacity for speech about 100,000 years ago This enabled him to communicate his ideas to his fellowmen and to plan and devise It gave him supremacy over all other animals and he made rapid progress To quote de Beer again "speech allowed him to formulate ideas and to exchange and store up his experience which memory converted into tradition, thus forming a link between the past and the present From that point through the power of reasoning, man was able to envisage deliberate aims A proof of this is to be found in the typology of his chipped flint implements But this experience in concept and execution, acquired little by little, is altogether different from the evolutionary advances which went before, since it is nor hereditary, but handed down in the form of instruction from one generation to another Education in being human or, in other words civilization is simply this tradition in the literal sense of 'handing down' whereby knowledge has been passed on and built up, as an acquired character' The education-based mechanism described as psycho-social evolution produces results far more quickly than does biological evolution This is a new mode of evolution based on education and research and on new tools, which has greatly accelerated progress in the material and technical planes

We may sum up Man evolved from anthropoid apes about a million years ago About 500,000 years ago he made rough tools out of stones for cutting the carcasses of animals and for flaying skins About 400,000 years ago, he discovered the use of fire Twenty thousand years ago, he domesticated wild animals allied to foxes and wolves, into dogs who became his companions in hunting wild animals About ten thousand years ago, he domesticated wild oxen, pigs and horses and started the cultivation of cereals like wheat About this time, he also invented the plough, pottery and basket-making Six thousand years ago he discovered the use of bronze, employed polished stone implements, developed a calendar and used mirrors About three to four thousand years ago, he discovered the process of smelting iron and manufactured iron axes which helped him in the clearance of forests About *400* B C he invented glass, pumps and astronomical instruments About *800* A D he made gunpowder and lenses About *1200* A D he invented the compass, and spectacles and learnt to distil alcohol About *1400* A D he started navigation with the aid of maps, he invented printing and fabricated guns

In the sixteenth century, a great exchange of cultivated plants took place between the old and the new world, thus changing the crop pattern providing new cereals fruits

and vegetables, and enriching human diet Between 1600-1700 A D, man invented the telescope and the microscope which provided him with a new vision of the starry sky and the unseen world of microscopic plants and animals From the beginning of the 19th century, he made phenomenal progress The steam age began about 1800 A D when the steam engine was invented and textile factories were started From 1830-1850 steamships, railways and telegraph were invented and towards the close of the 19th century electric light, the internal combustion engine and the automobile These ushered in the oil age in which fossil fuels, viz mineral oils, were commonly used In the first quarter of the 20th century, the aeroplane, wireless radio and fertilizers were invented This was followed by television In 1945 atomic fission was discovered and thus ushered in the atomic age

Man s greatest achievements are writing and printing which have enabled him to pass on his experiences to people separated from him in time and space Fast communication through radio and high speed jet aircraft greatly accelerated the dissemination of news and ideas With the development of rocketry, man pierced the mystery of space and will be landing on the moon in the near future These space flights have led to the discovery of new alloys which can withstand very high temperatures Progress that took millions of years to achieve was made in thousands of years, then in centuries and now in years Thus, man has progressed more during the past 150 years than the dinosaurs did during the 150 million years of their existence in the Mesozoic Era While it took fifty million years to alter the four toed *Eohippus* into the one-hoofed horse, in a generation man has invented the steamship, railroad and aeroplane The pace of change is in fact so fast that there is a great gap between material advancement and moral or ethical progress This gap is more evident in developed countries which have advanced materially, but are still on a low moral plane

Another fact worth noting is that the rate of reproduction of man has risen so high that by 2000 A D the population of the world is expected to be 4 billions This is not a new phenomenon in human history We have already stated in an earlier chapter that every major advance in technology has been followed by a population explosion The main challenge of the present age is how to feed, clothe and educate these vast numbers This will only be possible if resources which are being used in stockpiling atom bombs are diverted to peaceful purposes, to the building up of modern agriculture and industry in under-developed countries, improving human environment and providing education on a mass scale The goal of psycho-social evolution is a cultured and enlightened humanity, alert to both the truths of science and the beauty of art

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INDEX

(*Numbers in bold face indicate plates*)